RocketSTEM

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OSIRIS-REx to sample an asteroid

Exploring Europa

A new gold rush is on the horizon

Juno unlocking Jupiter's secrets

Pluto encounter data surprises

Centaurus over La Silla Observatory

The constellation of Centaurus hovers above the ESO 3.6-metre telescope in this spectacular shot from the La Silla Observatory in northern Chile. Surrounded by the mass of stars making up the Milky Way, the two bright stars right above the telescope dome are Alpha and Beta Centauri. Centaurus is home to the red dwarf star Proxima Centauri, our closest stellar neighbour and the target of a scientific and outreach project known as the Pale Red Dot campaign.

Credit: ESO/A.Santerne

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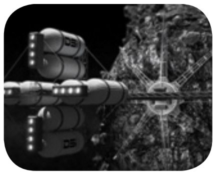

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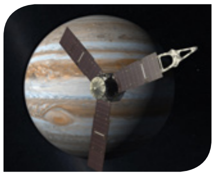

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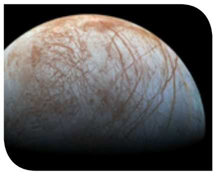

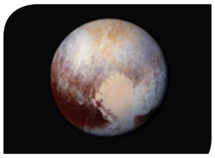

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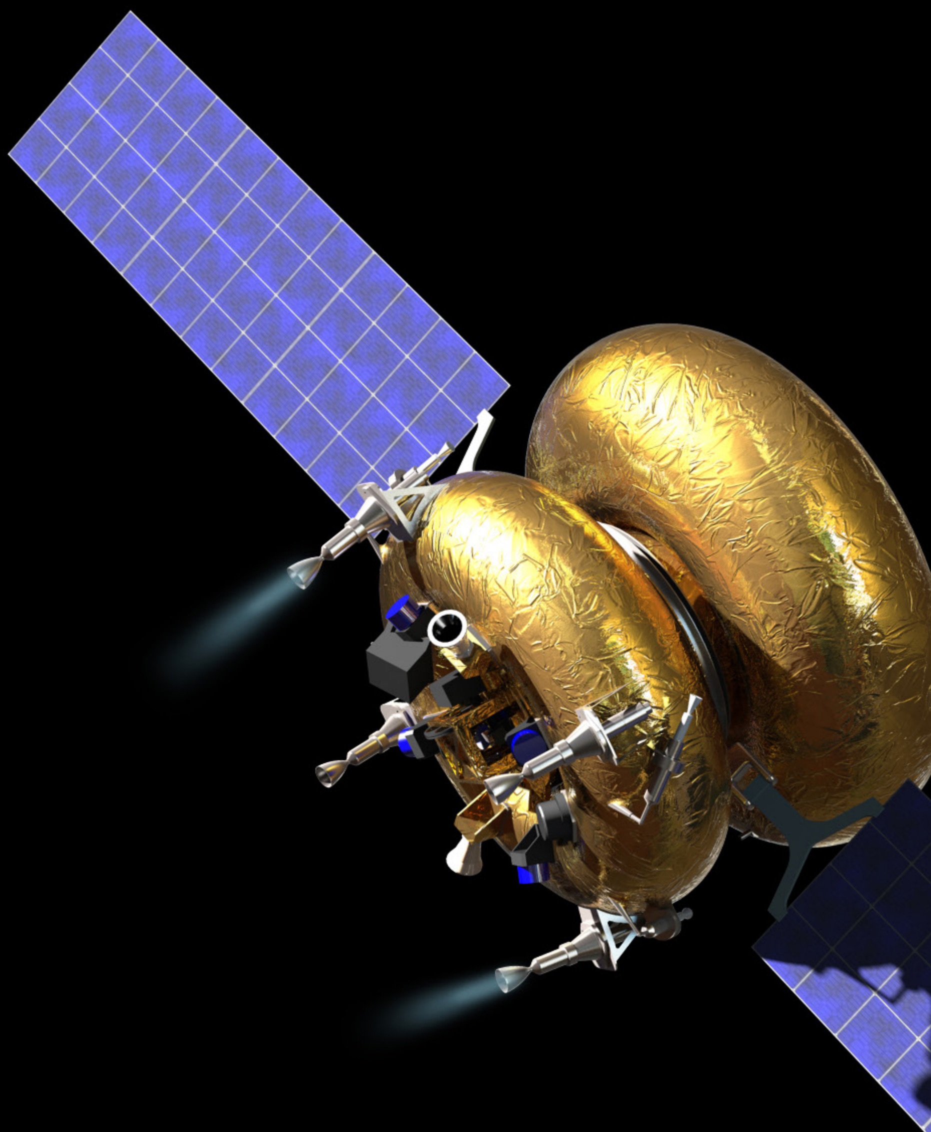
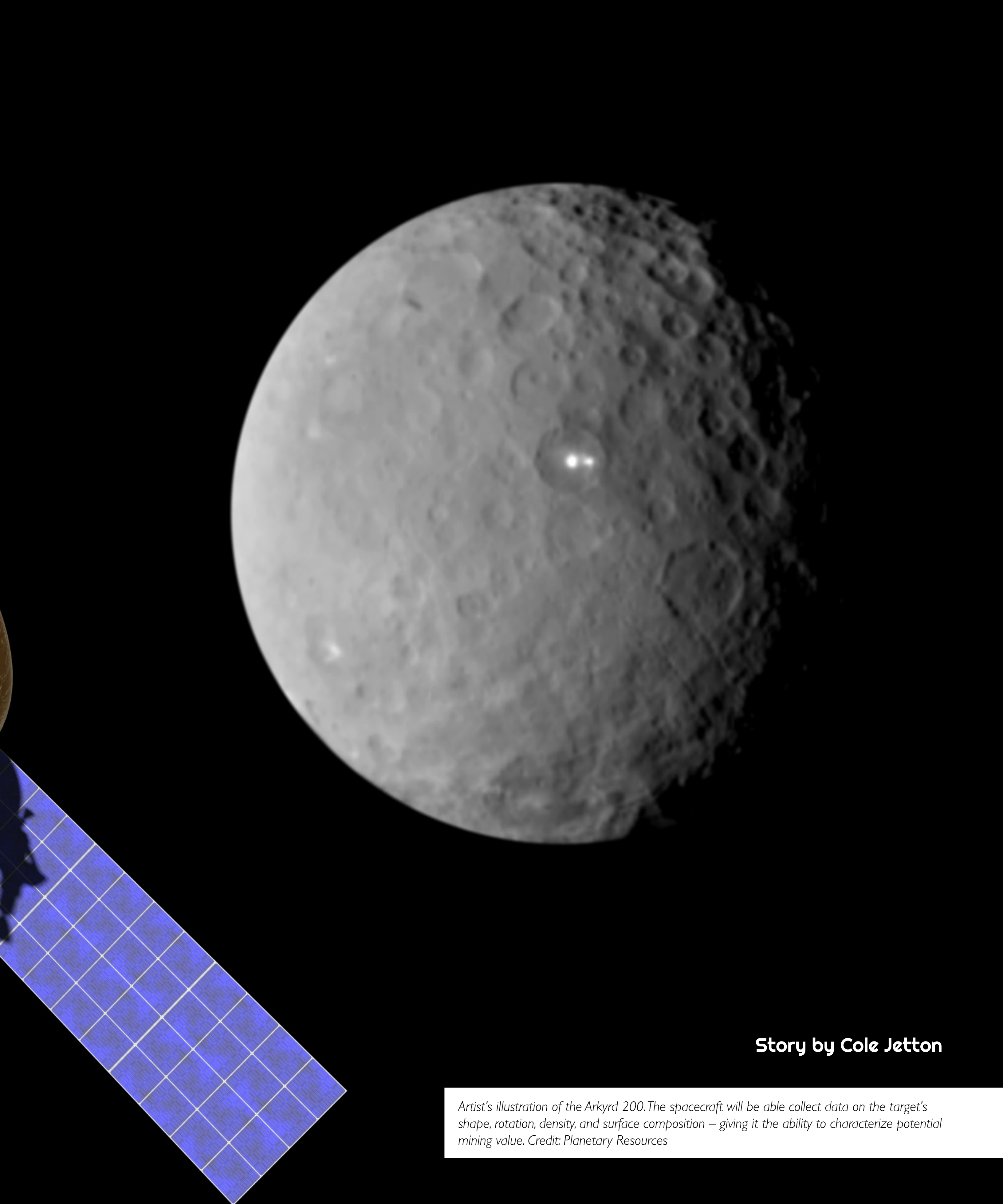
On the Covers: *Artist's concept shows the OSIRIS-REx spacecraft contacting Bennu. (front), and the NEEMO-21 crew undersea (back). Credits NASA*

Mining the sky



Prospecting for treasure within the solar system



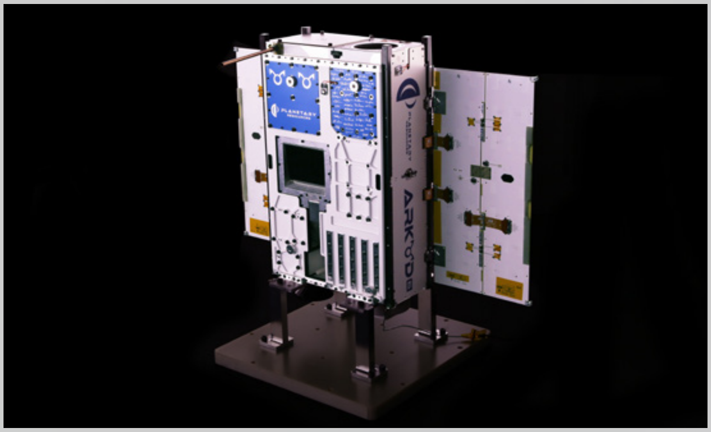
Story by Cole Jetton

Artist's illustration of the Arkyrd 200. The spacecraft will be able collect data on the target's shape, rotation, density, and surface composition – giving it the ability to characterize potential mining value. Credit: Planetary Resources

The current cost of space travel, on a price per mass basis, is astronomically high. All puns aside, this is a major economic barrier that must be overcome. If we are to send humans to Mars, or anyplace really, we're going to have to lower the cost of space travel. Companies are already looking towards cutting down launch costs, but there still exists the problem of mass. Currently we are limited only to what we can throw up there, so our ships must carry everything with them, including fuel. If we could build spacecraft up there, or process fuel in deep space, we could reduce mission cost significantly.

That's when we look up, seemingly towards the stars, but more specifically, towards the asteroids that scatter the solar system. We've known about their properties for years, with meteorites containing rare metals and comets spewing water across the sky. They're fragments of our early universe, remnants of a young system that never had a chance to harbor life. And now they're all ours.

A closer look at these rocks shows us an astonishing amount of diversity, and even greater potential. Their compositions spread over the periodic table, and their sizes range from pebbles to miniature worlds. Mining these asteroids will be an enormous challenge, but one that humanity is willing to take on. It starts with slow steps, with minimal funding, working towards a vision of a fully functional space economy. However before we can mine these asteroids, we must look to understand them.



The Arkyd 6 spacecraft, with the first ever commercial thermographic sensor, is ready for delivery to the launch pad for launch this year. Credit: Planetary Resources

NASA is where must turn to get some answers. Asteroids are very difficult to study, and since most research has been limited to what lands on Earth, there are still many unanswered questions. Soon, we may finally get some answers. Launching in September of 2016, OSIRIS-REx will begin its seven year mission to a carbonaceous asteroid to study it in detail, and then send a sample return mission back to Earth for further evaluation. This is a crucial first step, but its purpose is scientific, not industrial. If we're going to start prospecting asteroids then the private sector needs to get involved. The good news is, this already happened.

Two companies, Planetary Resources and Deep Space Industries, are embracing the possibilities at hand, and hope to be a part of what could very much be the next gold rush. Each company is in the process of designing

The Arkyd 3R shown being deployed from the ISS Kibo Airlock in July 2015. It successfully completed the objectives of testing core prospecting spacecraft technologies. Credit: NASA the first generation of asteroid mining spacecraft. In the short term, both companies are focused on mining one of the most abundant resources in the solar system: Water.

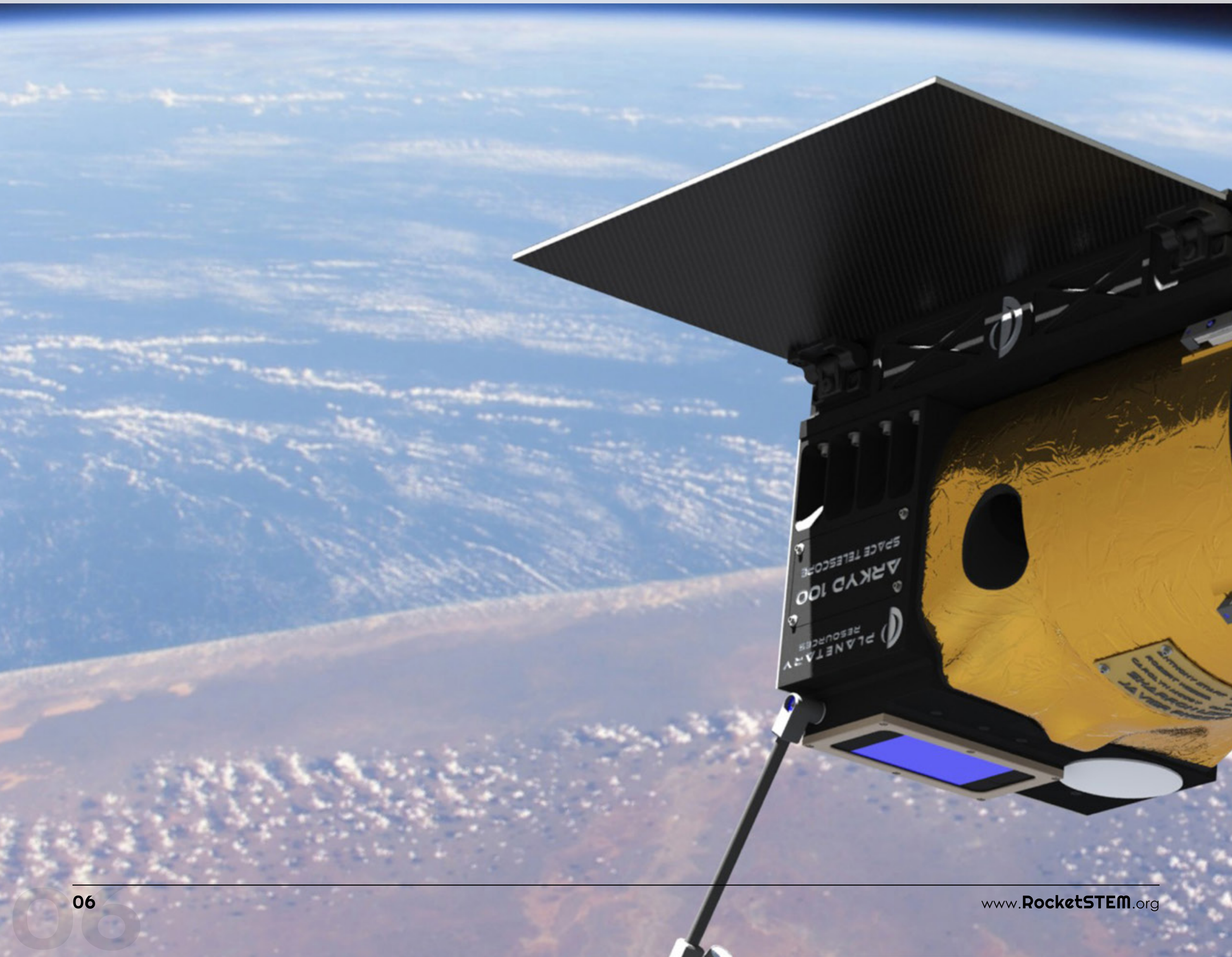
Water is one the most versatile molecules in the solar system. While there is obvious need of human consumption, water will be most likely used for fuel. The basic ingredients, hydrogen and oxygen, are the basis for many launch vehicles today, including NASA's upcoming Space Launch System. If we are able to manufacture rocket fuel in space, as both companies plan on doing, we will be able to reduce the cost of interplanetary travel. Both companies are currently moving forward with their plans to begin asteroid mining, and are aiming to begin water extraction by the early 2020's.

Deep Space Industries, often shortened to DSi, is currently working on Prospector-X. It aims to be the first commercial asteroid mining spacecraft. This CubeSat sized craft is planned to test the basic technologies in space, before being manufactured for prospecting and scouting missions. The spacecraft is equipped with two cameras, deep space avionics powered by solar cells, as well as their Comet-1 thruster. This small thruster uses water as fuel, expelling the superheated liquid to generate thrust.

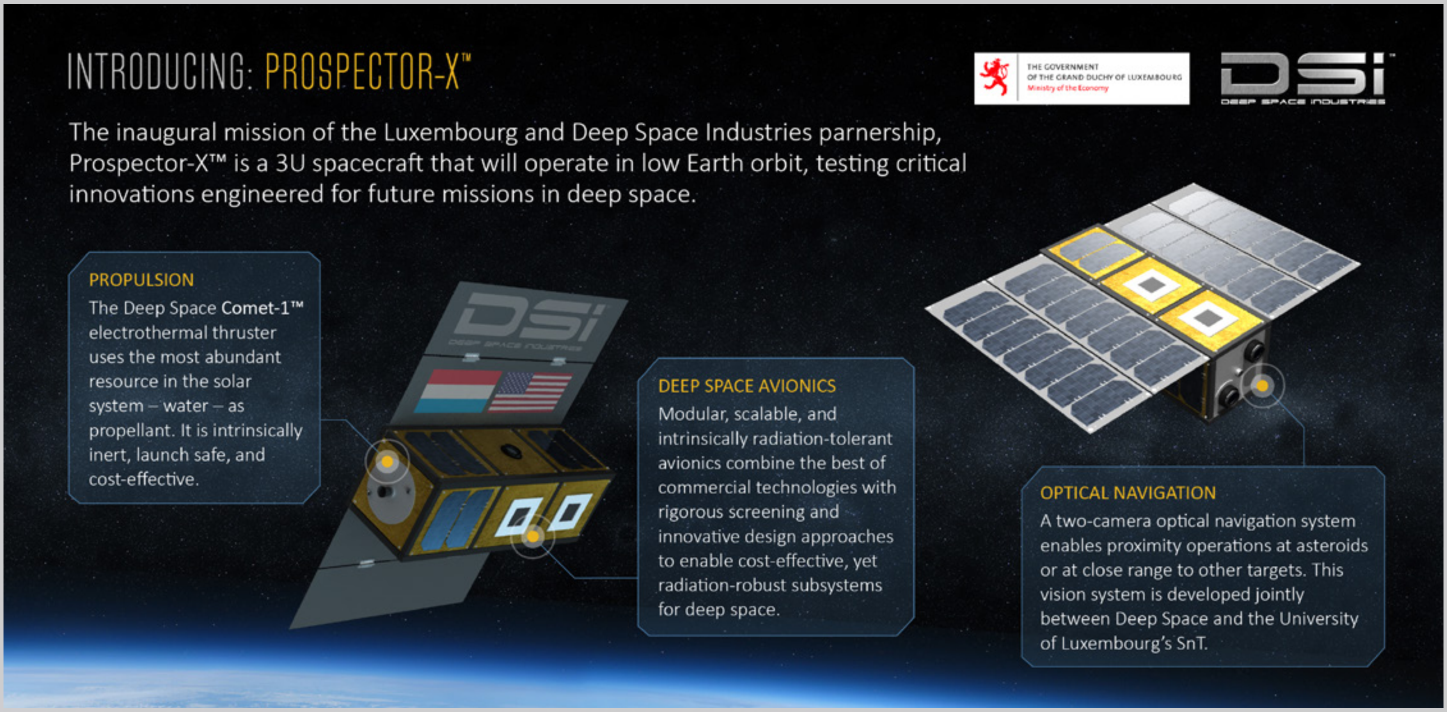
This craft, which is scheduled to launch in 2017, is a precursor to their aptly named Prospector-1. The next generation mining craft is scheduled to begin its mission by the end of the decade. This craft will be larger, weighing around 50 kg when fully fueled, and won't be confined to the dimensions given by cubesats. The hexagonal craft will be the first commercial interplanetary mining mission. After it launches, it will rendezvous with a near earth asteroid to observe its water content, map its surface, and touch down on the asteroid. This second mission builds off Prospector-X, and will test out DSi's technology in deep space.

Long term, Deep Space Industries hopes to prospect and mine near earth asteroids, and test in-space manufacturing technologies. Being able to process and manufacture metals is the eventual goal of Deep Space Industries, who look towards the stars with optimism. They strive to be a key piece of the mid to late 21st century.

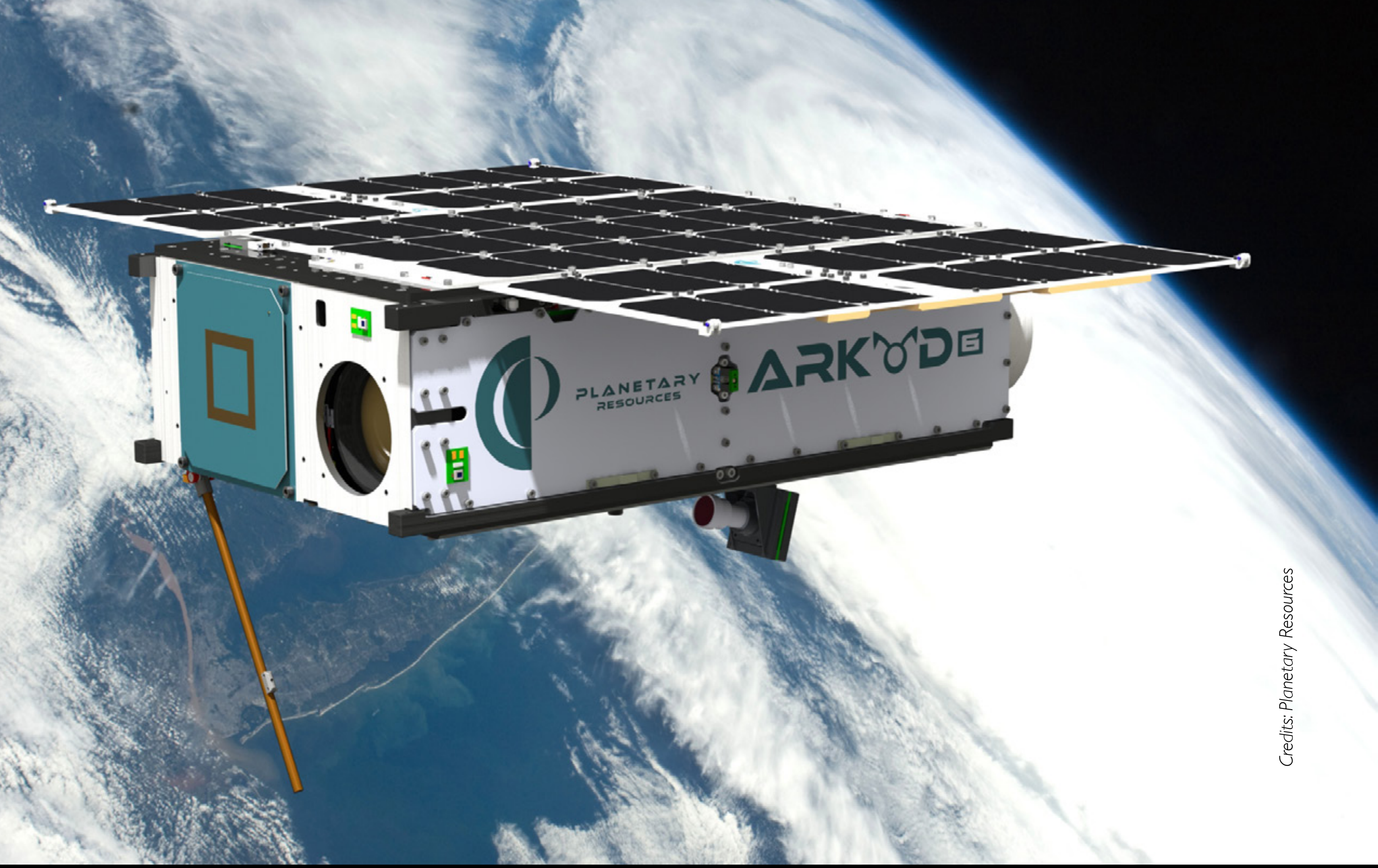
Planetary Resources has taken a step in a slightly different direction, putting its chips into first developing technologies for Low Earth Orbit, before testing out deep



Credit: Deep Space Industries

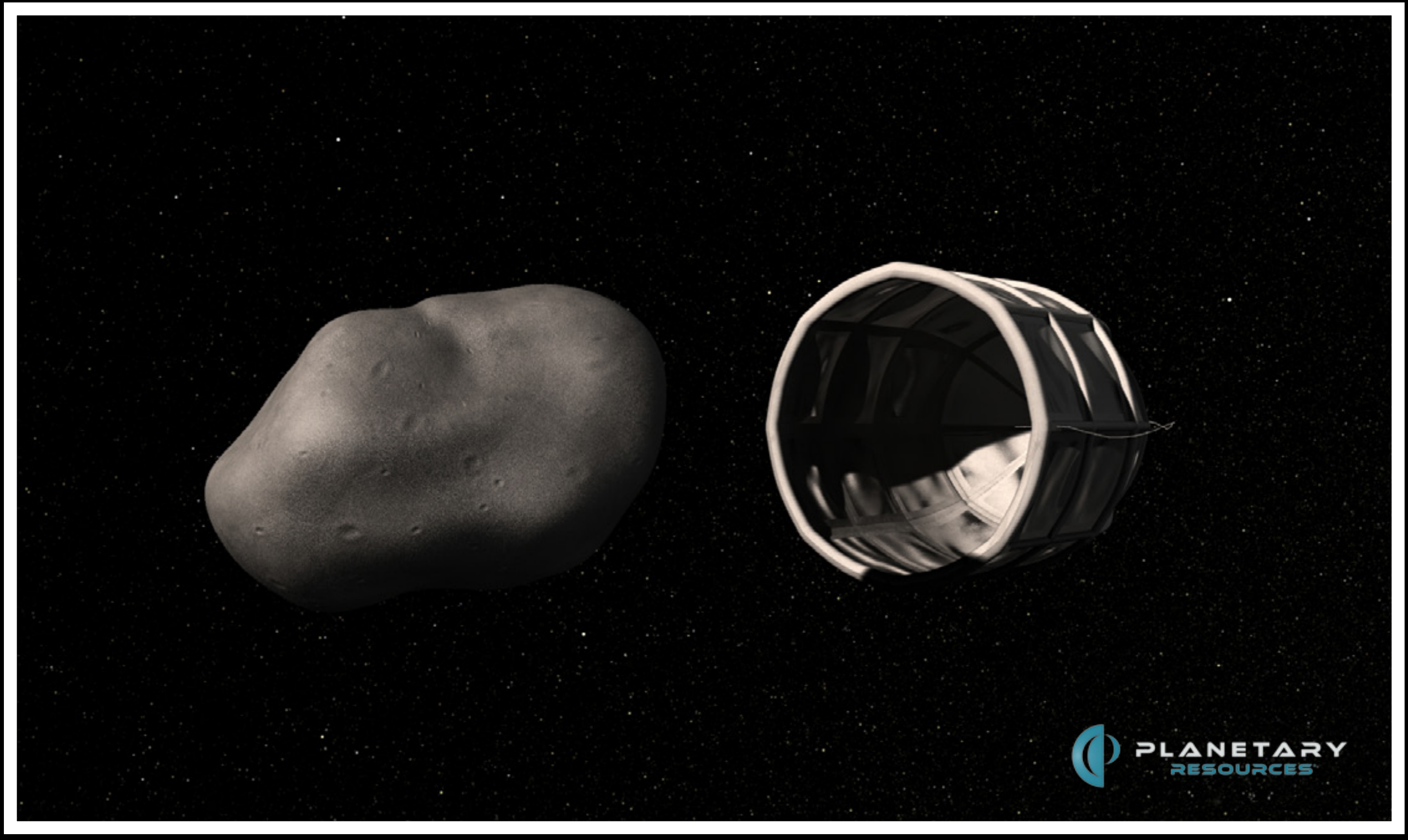


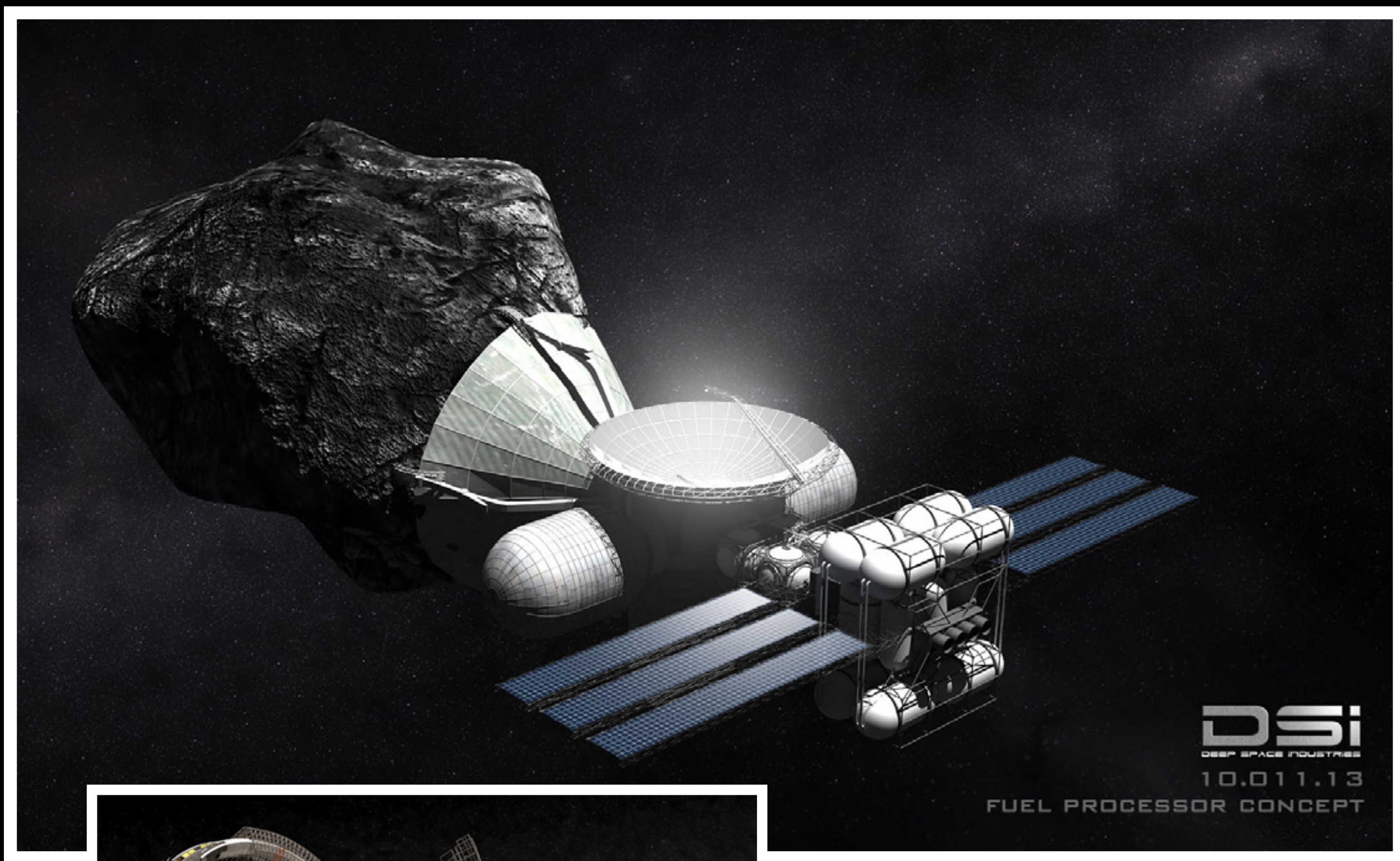
The Arkyd 100 will deliver valuable intelligence of the Earth, as well as test gathering compositional data of asteroids in preparation for our prospecting missions. Using only 10 Arkyd satellites in low Earth orbit, the Ceres constellation provides weekly data for any location on Earth at a lower cost than legacy multispectral data. Credit: Planetary Resources



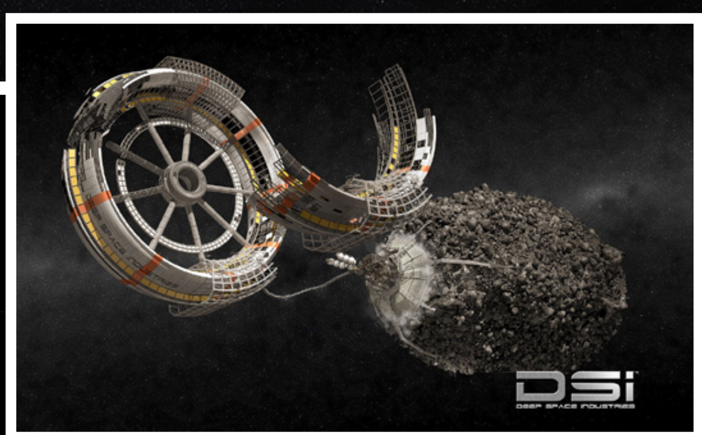
Credits: Planetary Resources

“Water is perhaps the most valuable resource in space. Accessing a water-rich asteroid will greatly enable the large-scale exploration of the solar system.”





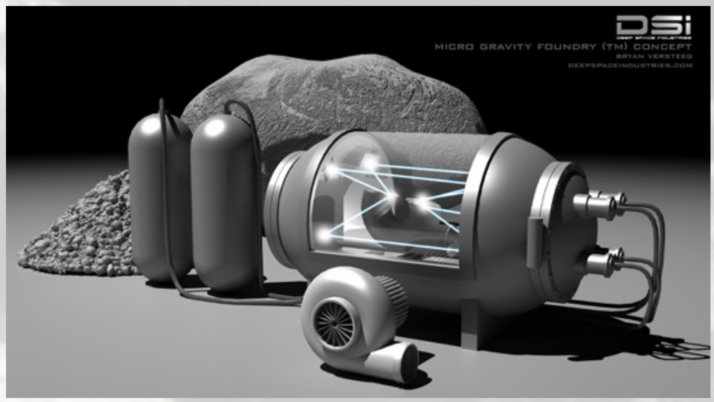
Credits: Deep Space Industries



Artist's illustration of DSi Prospector-1 on the surface of an asteroid. Credit: Deep Space Industries space systems. Their next spacecraft, the Arkyd-6, is slated for launch later this year. This will be their second CubeSat put into orbit after Arkyd-3 was deployed from the ISS last year.

They are testing vital camera, telecommunication, propulsion, and electric systems with their earlier craft. Planetary Resources is also planning on establishing an economic presence on earth with their Arkyd-100, which is the first step to their Earth observation focused Ceres program. Using Infrared and Hyperspectral imaging, Planetary Resources will be able to monitor temperature and water content, as well as mineral refineries and crops.

This demonstration in Earth orbit will give the engineers a chance to test out various key systems. Their long term spacecraft, Arkyd-200 and Arkyd-300, are aiming to rendezvous, observe, and prospect the asteroids up close.



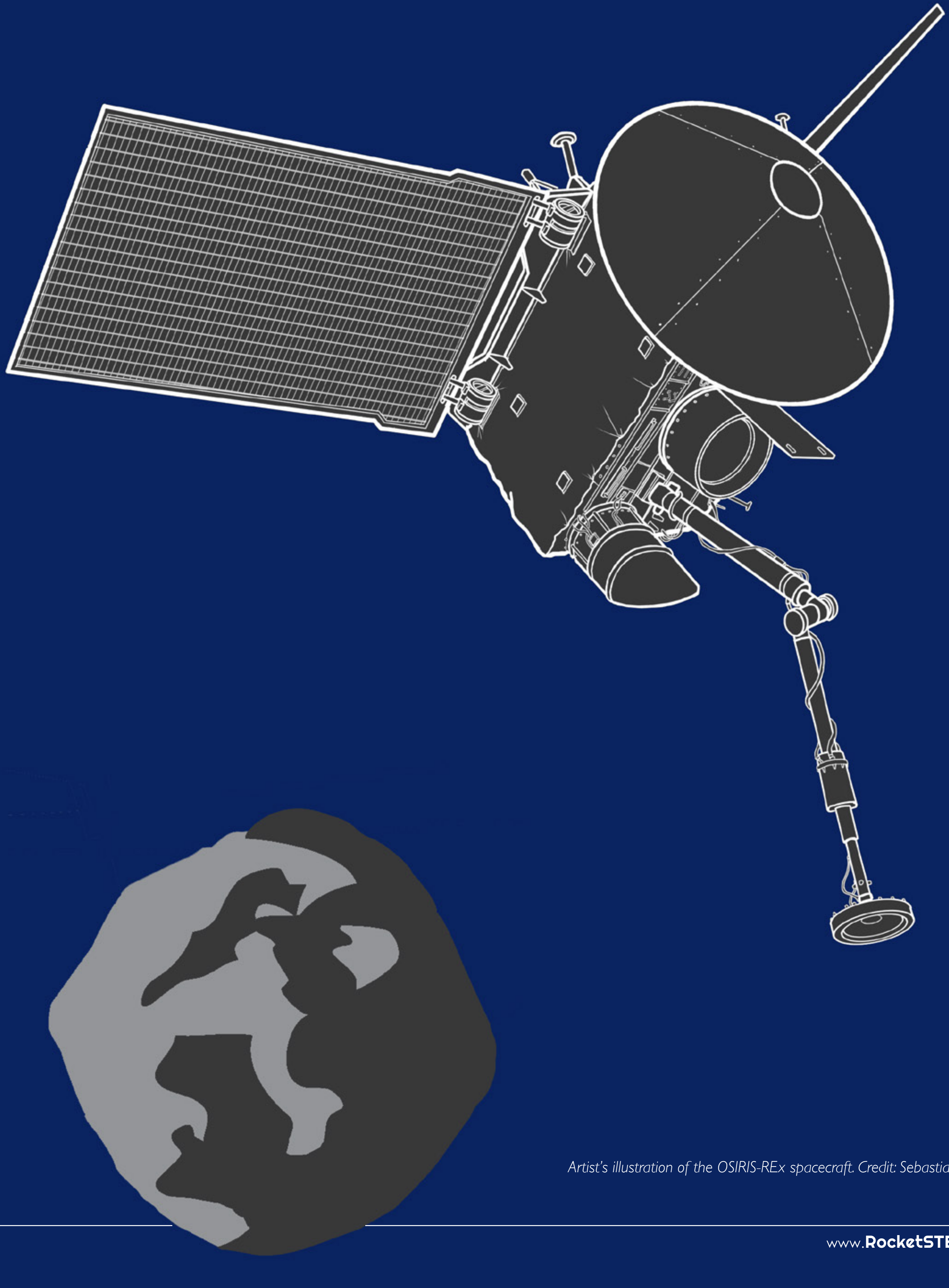
Artist's concept for micro gravity foundry. Credit: Deep Space Industries

This will allow the company to start surveying near earth asteroids for various resources, estimating their worth by observing their shape, size, and composition.

While a competition could be brewing between first two asteroid mining companies, a surprising force is driving the initial investment: Luxembourg. The small European country has been in a partnership with both companies and has pledged almost $230 million towards space mining companies. Currently, Luxembourg is working on a legal framework to incentivize more countries, and hopes to be the European powerhouse of space mining.

There are many challenges that we need to overcome, both technical and legal. But one by one, those walls will be torn down, humans have faced and overcome greater challenges before. The engineers of today are helping to build the infrastructure for the engineers of tomorrow, giving rise to new possibilities that today are still unimaginable. The ground work laid our by the space mining companies will help fuel a whole new economy in space, and could open the doors the rest of the solar system.

Interested in more? Check out our more in-depth article on NASA's asteroid mission that is about to launch. Start planning your own asteroid mission at Asterank.com, compare the worth of asteroids and start inventing your own ideas. Look further into these near future technologies with Deep Space Industries and Planetary Resources, and explore the first generation of space mining missions online.



Artist's illustration of the OSIRIS-REx spacecraft. Credit: Sebastian Kings

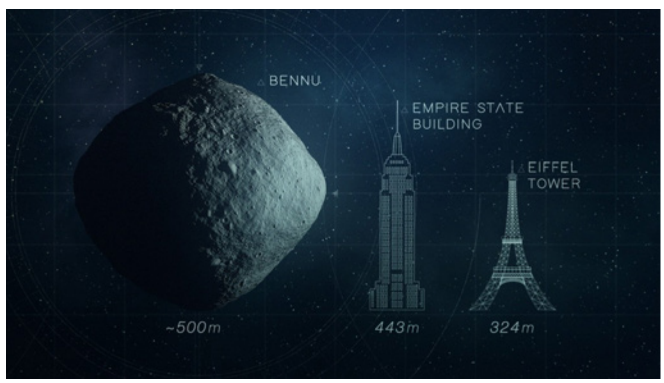
OSIRIS-REx

BRINGING HOME A PIECE OF AN ASTEROID

By Sherry Valare

Upon first hearing the name OSIRIS-REx, a picture of an unknown carnivorous dinosaur may come to mind. But OSIRIS-REx (Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer) is actually an acronym that names an upcoming asteroid exploration mission. A spacecraft will travel to an asteroid target in a near Earth orbit, perform scientific experiments, and become the first U.S. mission that gathers a sample from the surface to be returned back to Earth for further study.

This mission will try to answer some fundamental questions about our existence. What are the building blocks for our creation? What will the future bring?



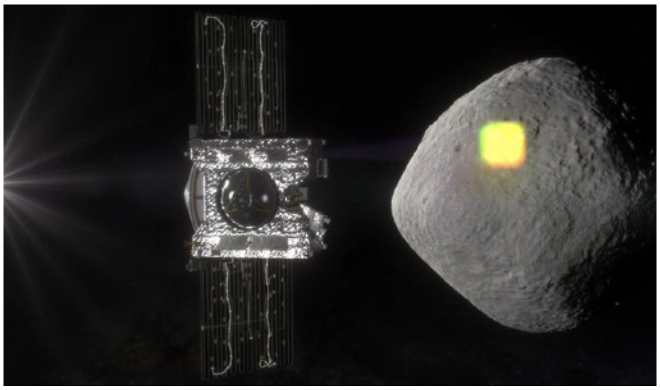
The size of asteroid Bennu, in comparison to two Earth landmarks. Credit: NASA's Goddard Space Flight Center Conceptual Image Lab.

To understand the OSIRIS-REx mission further, let's take a look at what an asteroid is. An asteroid is not the same as a comet or a meteoroid – there are differences in composition, origin of their formation, and size. An asteroid will have a diameter of at least one meter or more, and it is made of debris left after the solar system formed – primarily minerals and rock.

Many asteroids exist – millions, as a matter of fact. Most of the ones we know about reside in a place in the inner part of the solar system called the asteroid belt (which lies in between the orbits of planets Mars and Jupiter), and some even share an orbit with Jupiter.

Due to their rich composition, asteroids are a key to unlocking facts about our sun and planets' history. There isn't a huge difference between the makeup of a primitive asteroid today versus when they were formed almost 4.5 billion years ago, therefore they may hold answers to long standing scientific and philosophical questions about where life on this planet originated.

The carbon-rich asteroid chosen to be the focus of this mission is named Bennu. Bennu is a B-type asteroid with a diameter of around 500 meters. When it orbits, it comes very close to Earth every six years – about 0.002 AU (astronomical units) away. There are several reasons Bennu was picked – its distance from Earth, its size, and its composition are a few of them. But there is another much more dramatic reason to study this asteroid - because of how close it orbits near Earth, there is a high probability it could hit the planet sometime in the late 22nd century.



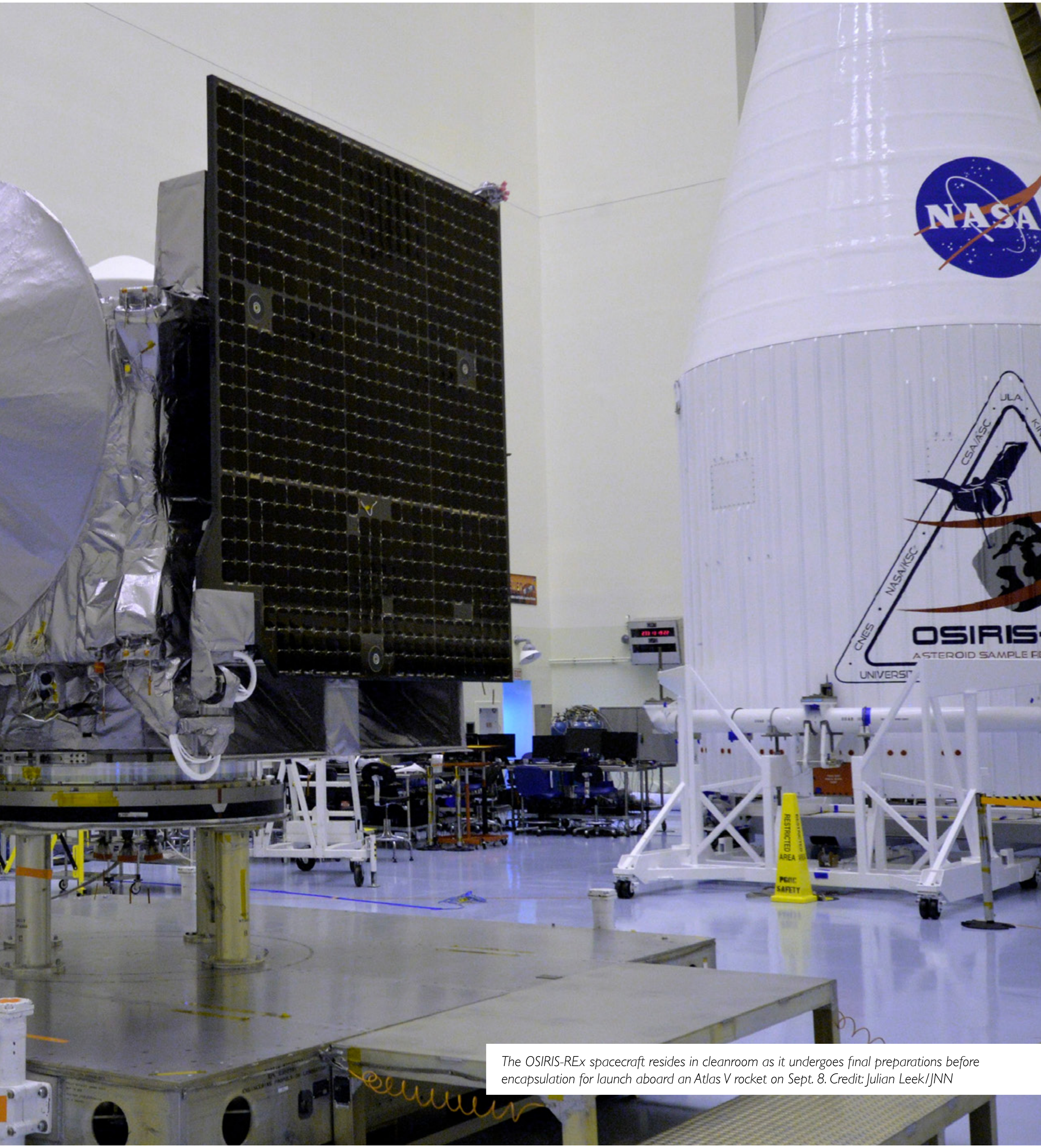
OSIRIS-REx will spend a year surveying Bennu before collecting a sample to return to Earth for analysis. Credit: NASA/Goddard/University of Arizona

Asteroids contain an abundance of natural resources, including water, organics, and precious metals that could be critical supporting components for future manned and robotic spacecraft traveling the solar system. Also, quite importantly, the chemical and physical makeup of Bennu will be essential information needed in the case of an imminent future impact with Earth and scientists would need to devise a plan to extinguish the threat.

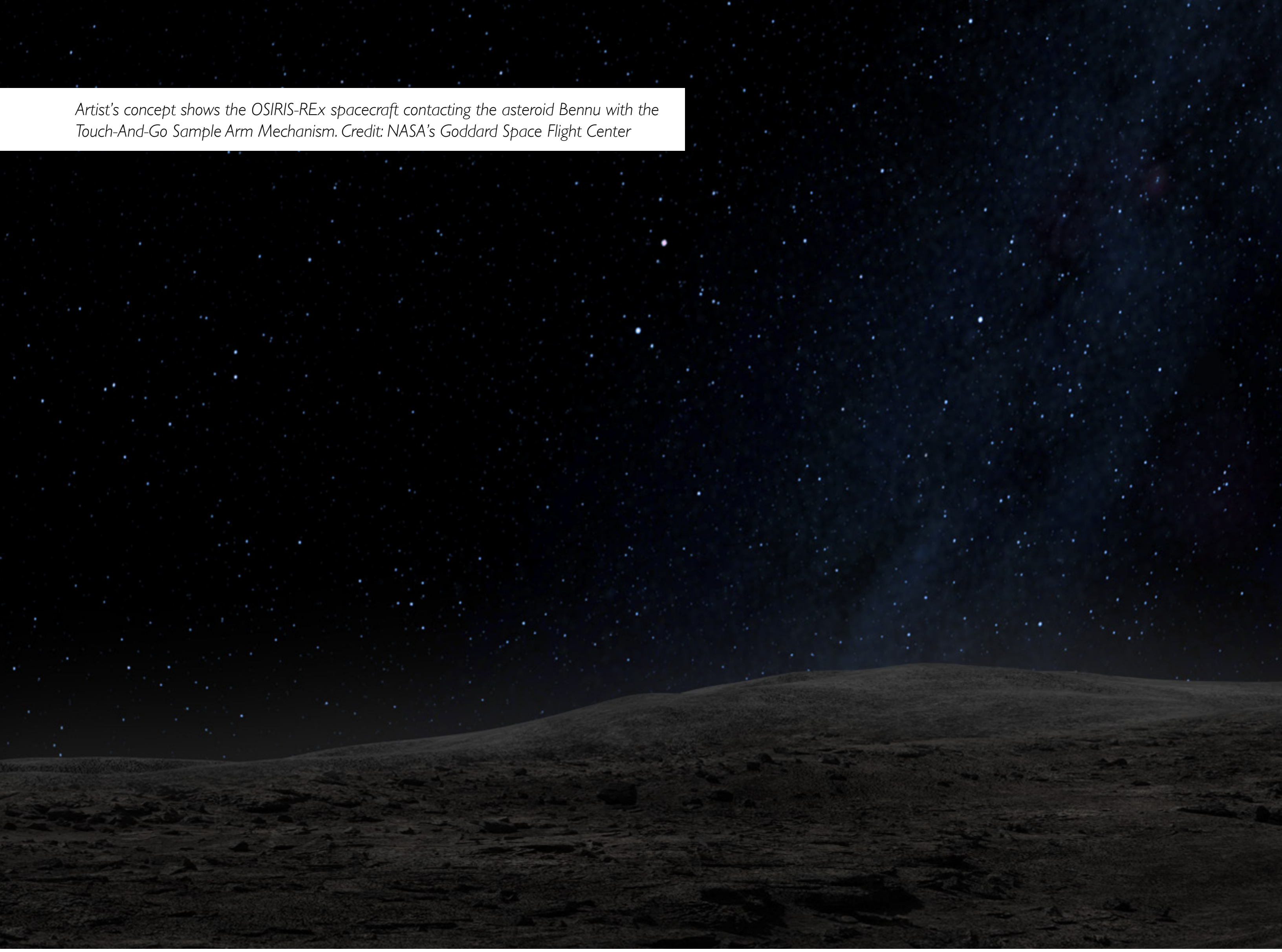
The primary science objectives for OSIRIS-REx include the following:

- Return and analyze a sample of Bennu's surface
- Map the asteroid
- Document the sample site
- Measure the orbit deviation caused by non-gravitational forces (the Yarkovsky effect)
- Compare observations at the asteroid to ground-based observations

The spacecraft will be packed atop an Atlas V 411



The OSIRIS-REx spacecraft resides in cleanroom as it undergoes final preparations before encapsulation for launch aboard an Atlas V rocket on Sept. 8. Credit: Julian Leek/JNN

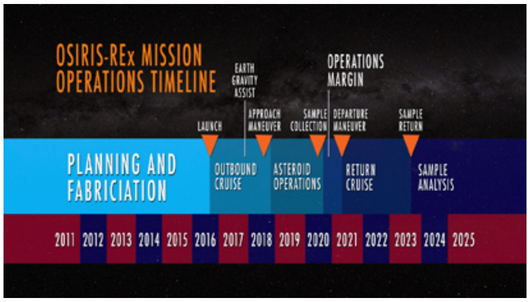


Artist's concept shows the OSIRIS-REx spacecraft contacting the asteroid Bennu with the Touch-And-Go Sample Arm Mechanism. Credit: NASA's Goddard Space Flight Center

rocket and is due to launch on September 8, 2016. It has a 34-day launch window. After three years of traveling – one of those spent orbiting the Sun before using Earth's gravitational field as an assist to get to Bennu – OSIRIS-REx will arrive.

A year long detailed survey will occur two months after the spacecraft nears Bennu and slows down – this is when possible sites for sample collection will be mapped out.

Once the site is chosen, the sampling arm on the spacecraft will extend towards the surface of Bennu and make contact for approximately five seconds. During this time, the arm will send out a burst of nitrogen gas which will stir up rocks and material on the surface so they can be captured by the sampler head. There is enough nitrogen in the machine for three attempts at collecting a sample, for a total of between 60 grams and 2 kilograms (2-70 ounces) of material.



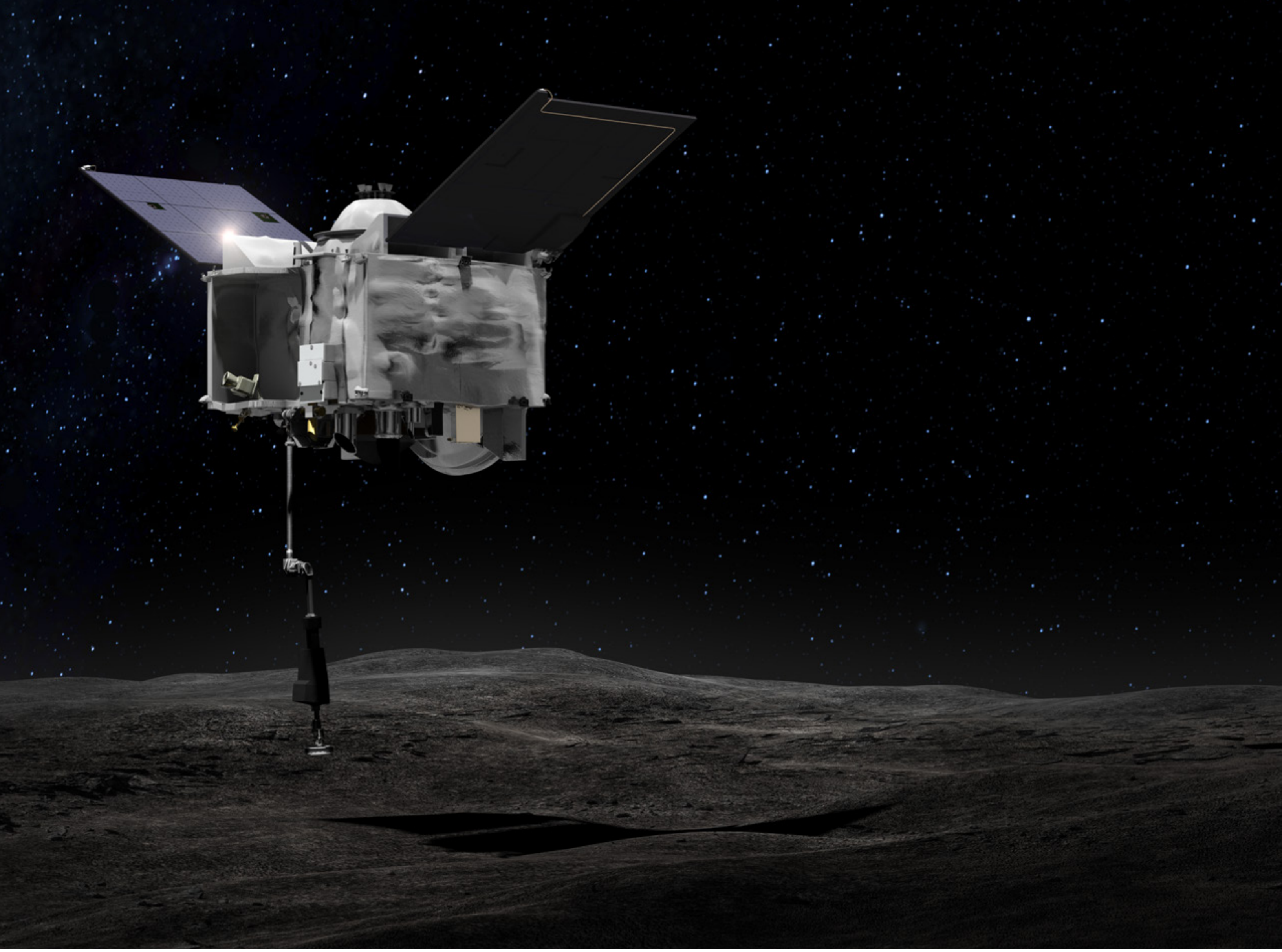
Credit: NASA

OSIRIS-REx will not begin its journey home until March 2021, when the window opens for it to leave the asteroid. It will take two and a half years for it to get back to Earth, arriving in September 2023.

The spacecraft will release the sample return capsule so it can enter the atmosphere and fall back to the ground in the Utah Test and Training Range. The science team will perform research on the sample for two years following its return, cataloging the sample and conducting analysis to achieve the goals of the mission.

At least three quarters of the sample will be remain preserved at NASA's Johnson Space Flight Center in Houston so that others may conduct research on it, as well, for generations to come.

For more information on OSIRIS-REx, please visit http://www.asteroidmission.org/.



Want to be an OSIRIS-REx ambassador?

What is an OSIRIS-REx ambassador?

An OSIRIS-REx ambassador is an individual trained to represent NASA's OSIRIS-REx mission to the public. The OSIRIS-REx Ambassadors Program is a volunteer program, which engages mission representatives with the public in informal venues such as science museums, community events, and mission activities. The purpose of the program is to provide trained, knowledgeable, and skilled volunteers for community engagement activities. Ambassadors communicate the excitement of the OSIRIS-REx mission. They provide information about NASA, University of Arizona Lunar and Planetary Laboratory, which leads the mission, Goddard Space Flight Center, Lockheed Martin, and instrument partners.

The program provides volunteer opportunities for:

- Community members to participate in the mission,
- Students to enhance their knowledge and skills,
- OSIRIS-REx scientists, engineers, managers, and technicians to share their mission stories.

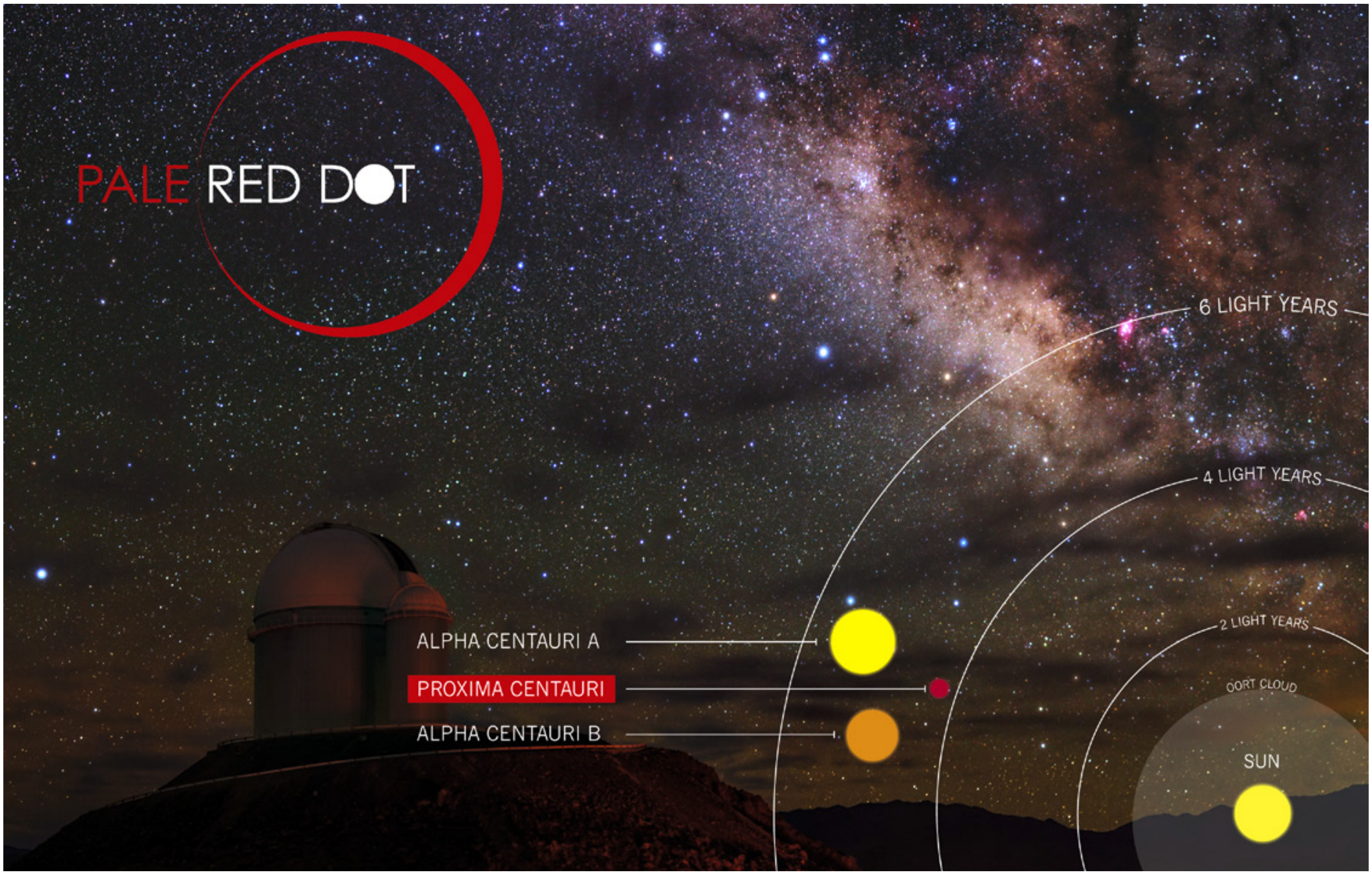
What does OSIRIS-REx provide for ambassadors?

The program not only helps the OSIRIS-REx mission engage students and the public with the mission and solar system exploration, but provides ambassadors with training in public engagement and mission content, access to breaking news about the mission, and interaction with team members and activities. Ambassadors can work in public venues or helping behind the scenes.

This ambassador program is modeled on and teams with other volunteer programs, including NASA's Solar System Ambassadors, and local efforts for even more opportunities.

How can you become an OSIRIS-REx ambassador?

The program has online and local sessions throughout the year. Contact OSIRIS-REx at orambgroup@orex.lpl.arizona.edu to sign up and get started as an ambassador.



Pale Red Dot was an international search for an Earth-like exoplanet around the closest star to us, Proxima Centauri. It used HARPS, attached to ESO's 3.6-metre telescope at La Silla Observatory, as well as other telescopes around the world. Credit: ESO/Pale Red Dot

Nearest star has planet in habitable zone

Earth-mass world spotted in orbit around Proxima Centauri

Astronomers using ESO telescopes and other facilities have found clear evidence of a planet orbiting the closest star to Earth, Proxima Centauri. The long-sought world, designated Proxima b, orbits its cool red parent star every 11 days and has a temperature suitable for liquid water to exist on its surface.

This rocky world is a little more massive than the Earth and is the closest exoplanet to us — and it may also be the closest possible abode for life outside the Solar System.

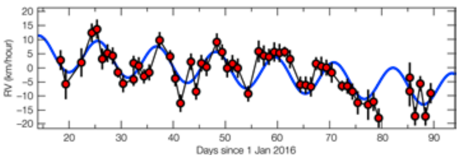
Just over four light-years from the Solar System lies a red dwarf star that has been named Proxima Centauri as it is the closest star to Earth apart from the Sun. This cool star in the constellation of Centaurus is too faint to be seen with the unaided eye and lies near to the much brighter pair of stars known as Alpha Centauri AB.

During the first half of 2016 Proxima Centauri was regularly observed with the HARPS spectrograph on the ESO 3.6-metre telescope at La Silla in Chile and simultaneously monitored by other telescopes around the world. This was the Pale Red Dot campaign, in which a team of astronomers led by Guillem Anglada-Escudé, from Queen Mary University of London, was looking for the tiny back and forth wobble of the star that would be caused by the gravitational pull of a possible orbiting planet.

As this was a topic with very wide public interest, the progress of the campaign between mid-January and April 2016 was shared publicly as it happened on the Pale Red Dot website and via social media. The reports were accompanied by numerous outreach articles written by specialists around the world.

Guillem Anglada-Escudé explains the background to this unique search: "The first hints of a possible planet were spotted back in 2013, but the detection was not convincing. Since then we have worked hard to get further observations off the ground with help from ESO and others. The recent Pale Red Dot campaign has been about two years in the planning."

The Pale Red Dot data, when combined with earlier observations made at ESO observatories and elsewhere, revealed the clear signal of a truly exciting result. At times Proxima Centauri is approaching Earth at about 5 kilometres per hour — normal human walking pace — and at times receding at the same speed. This regular pattern of changing radial velocities repeats with a period of 11.2 days. Careful analysis of the resulting tiny Doppler shifts showed that they indicated the presence of a planet with a mass at least 1.3 times that of the Earth, orbiting about 7 million kilometres from Proxima Centauri — only 5% of the Earth-Sun distance.



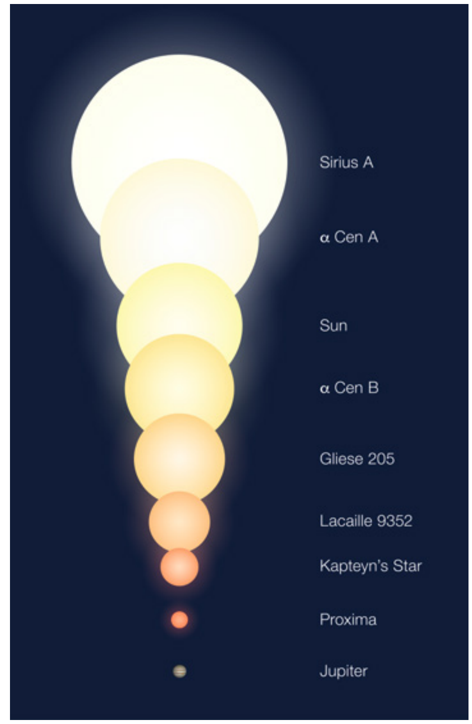
This plot shows how the motion of Proxima Centauri towards and away from Earth is changing with time. Credit: ESO/G. Anglada-Escudé

Guillem Anglada-Escudé comments on the excitement of the last few months: "I kept checking the consistency of the signal every single day during the 60 nights of the Pale Red Dot campaign. The first 10 were promising, the first 20 were consistent with expectations, and at 30 days the result was pretty much definitive, so we started drafting the paper!"

Red dwarfs like Proxima Centauri are active stars and can vary in ways that would mimic the presence of a planet. To exclude this possibility the team also monitored the changing brightness of the star very carefully during the campaign using the ASH2 telescope at the San Pedro de Atacama Celestial Explorations Observatory in Chile and the Las Cumbres Observatory telescope network. Radial velocity data taken when the star was flaring were excluded from the final analysis.

Although Proxima b orbits much closer to its star than Mercury does to the Sun in the Solar System, the star itself is far fainter than the Sun. As a result Proxima b lies well within the habitable zone around the star and has an estimated surface temperature that would allow the presence of liquid water. Despite the temperate orbit of Proxima b, the conditions on the surface may be strongly affected by the ultraviolet and X-ray flares from the star — far more intense than the Earth experiences from the Sun.

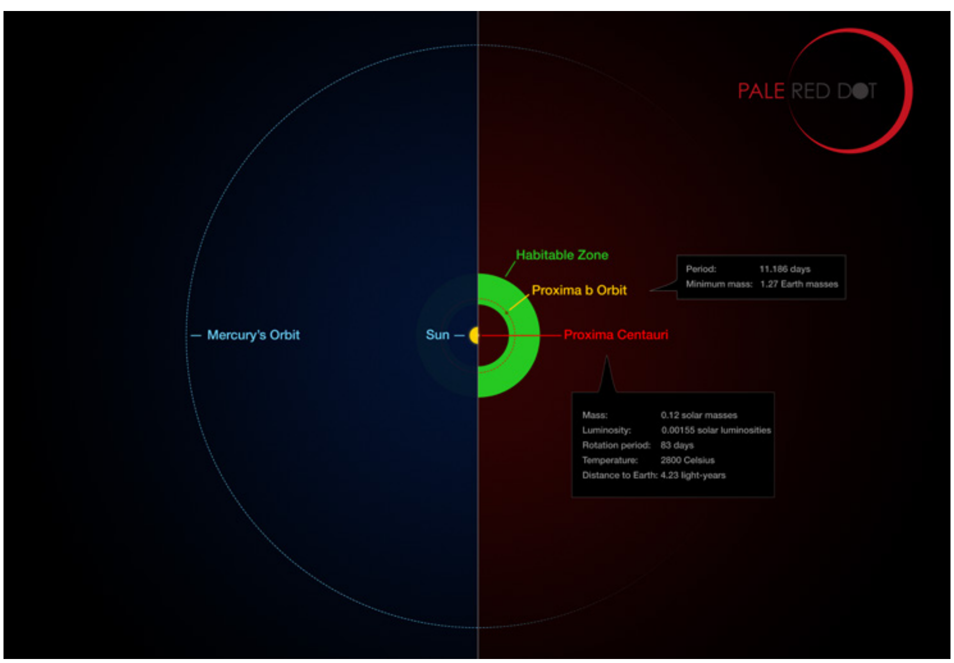
Two separate papers discuss the habitability of Proxima b and its climate. They find that the existence of liquid water on the planet today cannot be ruled out and, in such case, it may be present over the surface of the planet only in the sunniest regions, either in an area in the hemisphere of the planet facing the star (synchronous rotation) or in a tropical belt (3:2 resonance rotation). Proxima b's rotation, the strong radiation from its star and the formation history of the planet makes its climate quite different from that of the Earth, and it is unlikely that Proxima b has seasons.



The relative sizes of a number of objects, including the three (known) members of Alpha Centauri triple system and some other stars. The Sun and planet Jupiter are also shown for comparison. Credit: ESO

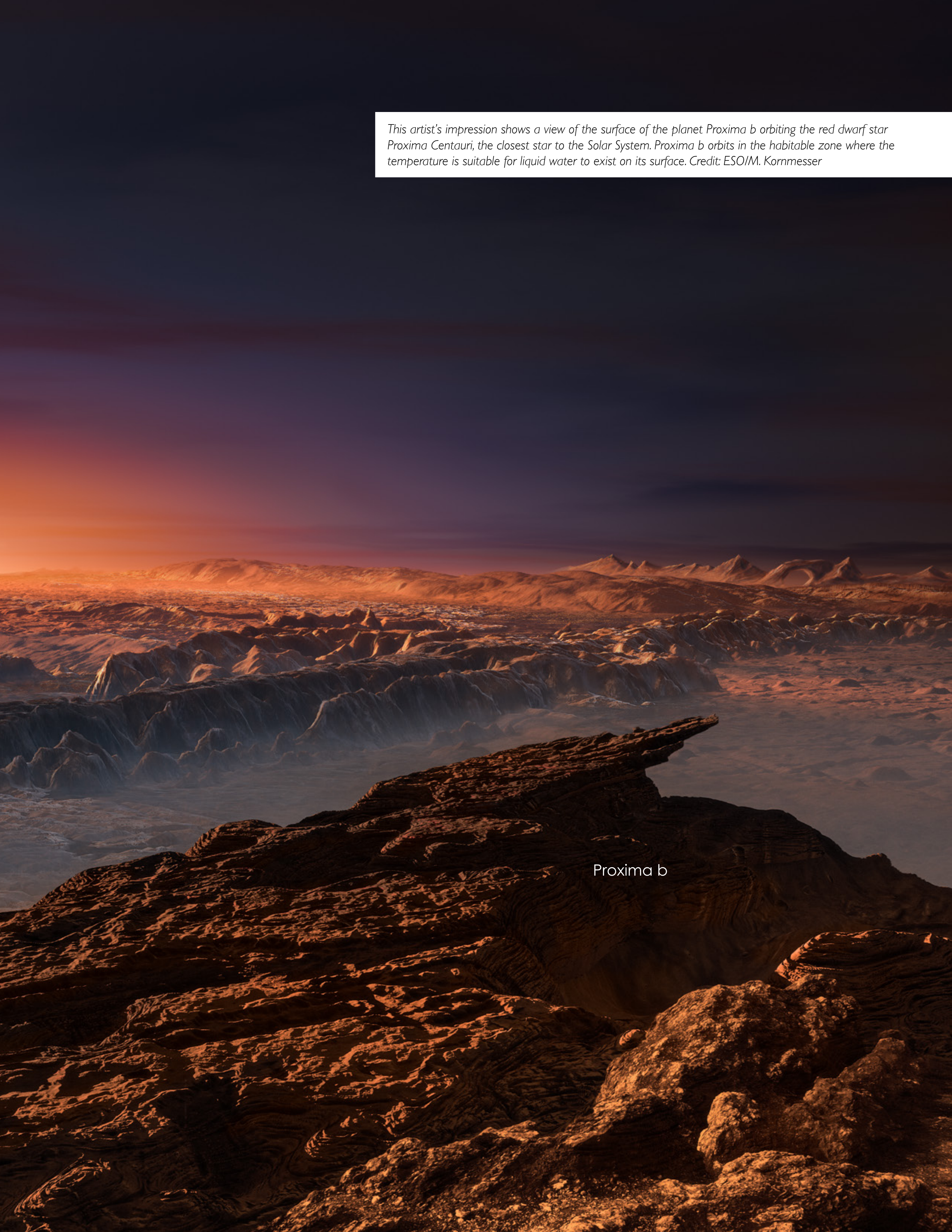
This discovery will be the beginning of extensive further observations, both with current instruments and with the next generation of giant telescopes such as the European Extremely Large Telescope (E-ELT). Proxima b will be a prime target for the hunt for evidence of life elsewhere in the Universe. Indeed, the Alpha Centauri system is also the target of humankind's first attempt to travel to another star system, the StarShot project.

Guillem Anglada-Escudé concludes: "Many exoplanets have been found and many more will be found, but searching for the closest potential Earth-analogue and succeeding has been the experience of a lifetime for all of us. Many people's stories and efforts have converged on this discovery. The result is also a tribute to all of them. The search for life on Proxima b comes next..."



This infographic compares the orbit of the planet around Proxima Centauri (Proxima b) with the same region of the Solar System. Proxima Centauri is smaller and cooler than the Sun and the planet orbits much closer to its star than Mercury. As a result it lies well within the habitable zone, where liquid water can exist on the planet's surface. Credit: ESO/M. Kornmesser/G. Coleman


Alpha Centauri AB
Proxima Centauri



This artist's impression shows a view of the surface of the planet Proxima b orbiting the red dwarf star Proxima Centauri, the closest star to the Solar System. Proxima b orbits in the habitable zone where the temperature is suitable for liquid water to exist on its surface. Credit: ESO/M. Kornmesser

Your ticket to space

Space Shuttle Atlantis on display at the KSCVC.

Kennedy Space Center Visitor Complex

By Lloyd Campbell

If you've never been to the Kennedy Space Center Visitor Complex and you are reading this article, well you owe it to yourself to make that trip at some point. If you have been there before, but not in a few years, I'd suggest that it's time for a return trip.

The complex has undergone numerous changes and updates, not to mention the addition of the Space Shuttle Atlantis exhibit. The entire facility is top notch and offers you the opportunity to see and learn about actual spacecraft, rockets, spacesuits, and many more interesting artifacts.

In the Rocket Garden you will find many of the early launch vehicles used by NASA for both unmanned and manned spaceflight. From the 77-foot tall Juno rocket used to launch some of the earliest satellites, a Redstone and an Atlas that were used for the Mercury launches, a Titan used in the Gemini Missions, right up through the 223-foot Saturn 1B used to test fly Apollo spacecraft into Earth orbit, and many in between rockets abound in the garden.

FACTLET

More than 1.5 million people per year visit the Kennedy Space Center Visitor Complex.

Each rocket has information near it explaining what it is and what it was used for. You'll also find simulated Mercury, Gemini, and Apollo Capsules that you can climb in to see just how cramped those vehicles were. There is also an actual Crew Access Arm from the Apollo program that you can walk down just as the Apollo 11 astronauts did on their way to the Moon.

You can meet a real-life astronaut at the Astronaut Encounter where an actual astronaut speaks a couple of times a day. After the presentation, the astronaut normally has time to take your picture with him or her, along with a handshake and greeting! Also available in the Astronaut Encounter theater is a new presentation, "Eyes on the Universe: NASA'S Space Telescopes," a 3D 4K video presentation which takes you back 13 billion years using images from the Hubble Space Telescope.

Also in the main visitors compex there is an IMAX theater showing two different large-format films throughout the day, as well as

The former NASA Countdown Clock, the Rocket Park, and the sloping Kennedy fountain greet visitors as they enter the KSC Visitor Complex.

the Astronaut Memorial where fallen heroes of the space program are memorialized, and a children's playdome where kids can play in a space themed playground. In the future, the revamped Astronaut Hall of Fame will be opening just outside of the Rocket Garden.

While there, be sure to take the free bus tour. It will take you onto the actual Kennedy Space Center property where you get to see the massive Vehicle Assembly Building, the Launch Control Center, and other buildings in the main KSC area, Then you'll head out along the massive crawlerway and pass by the launch pads used to launch 135 Space Shuttle missions and every manned mission, to date, that has gone to the Moon. If you're lucky there might be a NASA crawler transporter outside for you to see.

At the end of the bus tour you'll stop at the Saturn V center. You'll see two presentations, the first in a three-screen theater that covers the early space race with Russia, starting with Sputnik, up through the early Apollo flights up until Apollo 8. Next you'll move into a second theater, which contains the actual launch control center that was used to launch Apollo 8, the first manned mission to orbit the Moon.

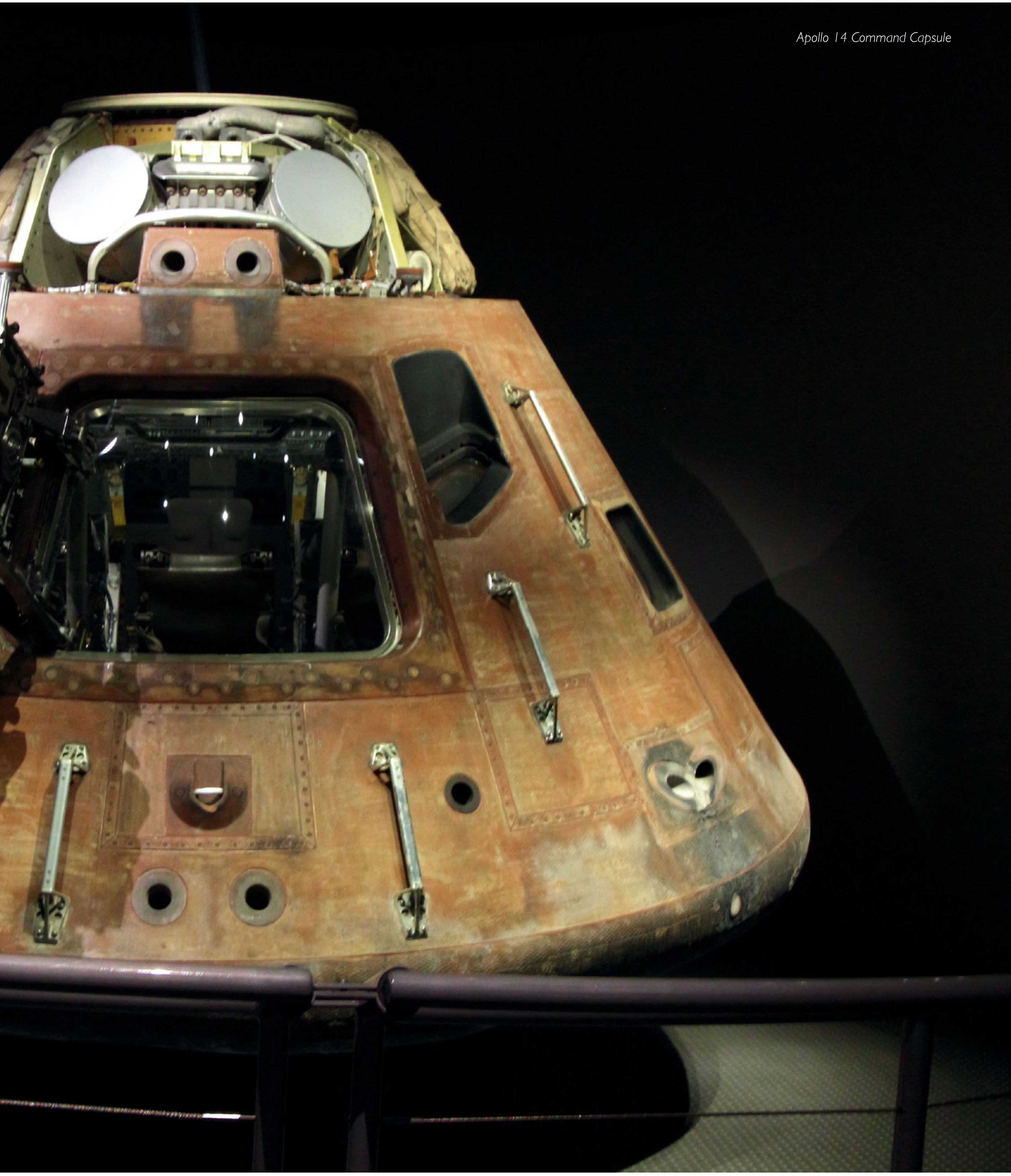
FACTLET

The Apollo 14 Command and Service Modules were named Kitty Hawk, while the Lunar Module was named Antares.

The presentation takes you through the countdown to launch of the mighty Saturn V that propelled Frank Borman, Jim Lovell, and William Anders to their historic spaceflight.

Following that presentation you'll enter the main area of the Saturn V building where you'll see a fully restored Saturn V rocket laid down end to end. Taking up more than the length of a football field, the mighty rocket alone is a lot to take in. Along the way through the building while looking at the Saturn V you'll find information on the power that the vehicle made, what it took to move the huge vehicle, a brief synopsis of each Apollo mission, a scale model explaining the different stages of the Saturn V, and much more.

This facility also has the original Apollo 14 Capsule that took Command Module Pilot Stuart Roosa, Lunar Module Pilot and



Apollo 14 Command Capsule


BIG IS BIG?
ng men on the Moon and returning them
to Earth required a launch vehicle of
edented strength and size. NASA
ed to the challenge by developing
powerful and most massive
cket in American history.
almost 6.2 million pounds, a
Saturn V was as heavy as
g 747 Jumbo Jets.
E ?
TO MOVE
A GIANT...
INSIDE THE

Saturn V Rocket separated into each stage moonwalker Edgar Mitchel, and Commander and moonwalker Alan Shepard to the Moon and back. There is an original Lunar Module that would have been used to land on the surface, a Lunar Rover simulator, actual Moon rocks, spacesuits, and other great artifacts. You can even touch a small piece of a real Moon rock.

While all of the visitors complex has amazing displays and great artifacts, the latest and perhaps the most spectacular of all the exhibits is the Space Shuttle Atlantis exhibit which opened in 2013. The 90,000 square foot facility is reported to have cost $100 million to build and it showcases the Space Shuttle program like no other facility has done to date.

FACTLET

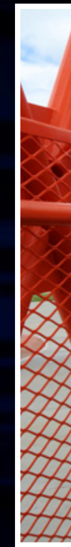
The Space Shop located inside KSCVC is the largest retail store in the world devoted to space-themed merchandise.

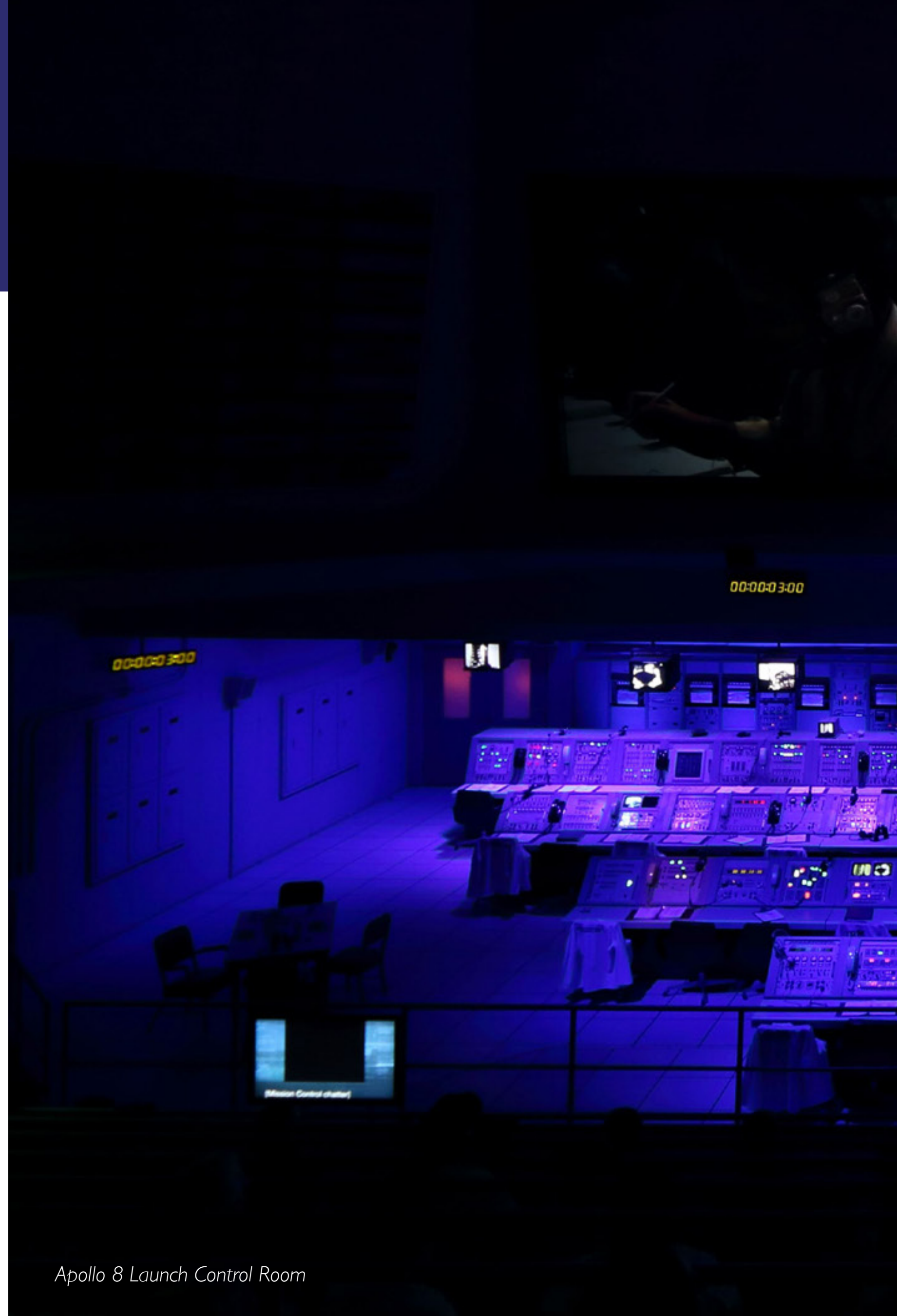
The exhibit is in the main visitors center area. You can't miss it. Out in front is a massive, 184-foot tall full-size replica of the Solid Rockets Boosters and Fuel tank used to launch the orbiter into space. You'll be able to see the stack in the distance as you drive out to the visitors' center and it can be spotted fairly easily all the way back in Titusville more than 10 miles away. While you are looking up at the massive stack, take a moment and look down, the entranceway is lined with actual rocks from the NASA crawlerway which the mighty Saturn V rockets that took astronauts to the Moon rolled out to the launch pads on, and every Space Shuttle flight rolled over those rocks as well.

Once inside the building, you'll walk along a slight ascent with images of the shuttle, astronauts, and more to look at on your way. If it's not busy you can take some interesting photographs of you and/or your family members with many of these images. When you near the top there are a massive set of windows that overlook the tank and boosters outside and you can see almost the entire main visitor's center. The view gives you something extra to look at until you head into the theater.

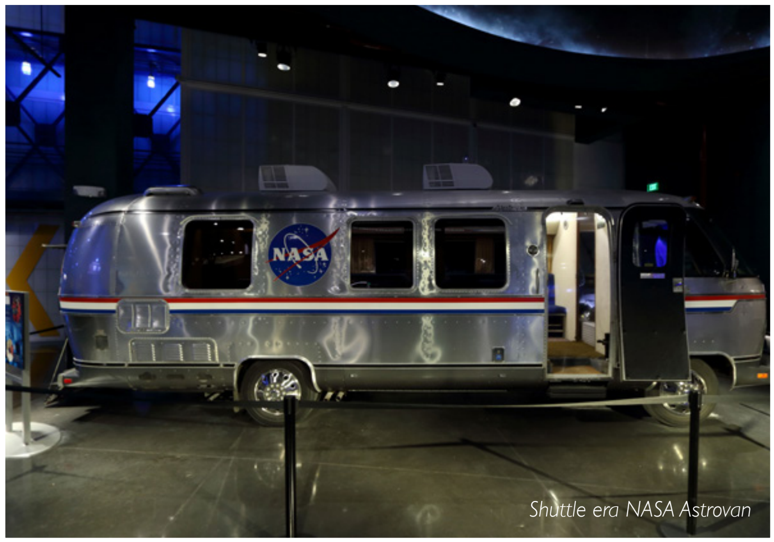
Once inside the theater you will be treated with the story of how the shuttle was conceived, built and ultimately flown and

Unflown Lunar Module




Apollo 8 Launch Control Room


Apollo Crew Access Arm



Shuttle era NASA Astrovan

Apollo Command Module and Service Module


Mitchell

maintained. The presentations culminate with the unveiling of the orbiter Atlantis.

Atlantis is displayed at an angle of 43.21 degrees (think about that number for a minute) mounted to support pillars using the attachment points for the external tank. The payload bay doors are open and the CanadaArm is deployed, simulating what the vehicle would have looked like on orbit. The orbiter still shows the effects of reentry with plasma scars still on the thermal protection blankets and tiles. If you brought a camera with a decent zoom, look through the crew compartment windows and you can see some of the many switches inside the compartment.

On the wall at the engine end of the orbiter is a massive 20 ft. by 100 ft. LED backdrop that displays the Earth, an orbital sunrise, and many other unique visual cues that add to the experience. Look up, there's an Astronaut with a Manned Maneuvering Unit on.

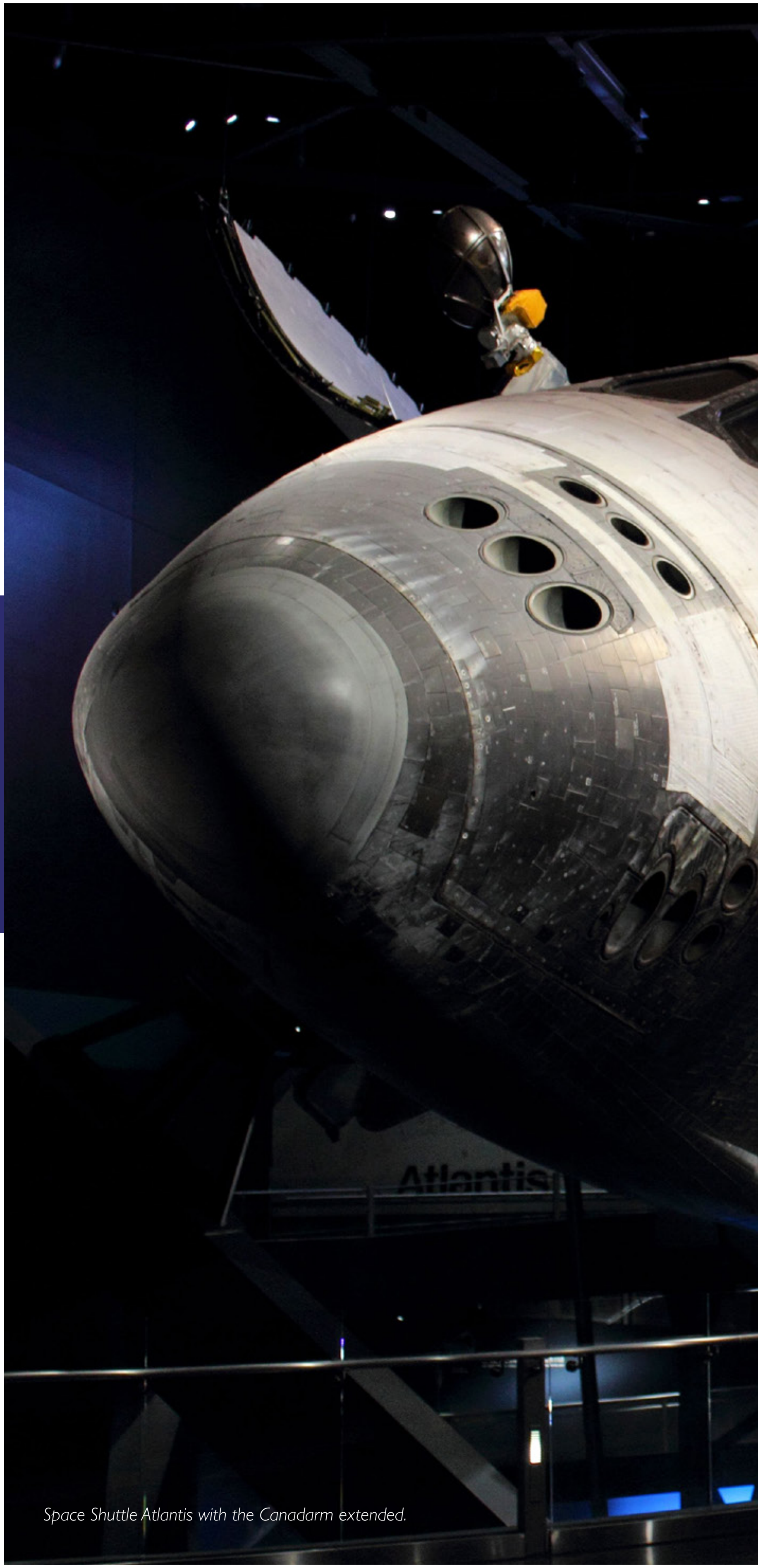
FACTLET

Atlantis flew 33 missions during its 26 year career, spending a total of 307 days in space and traveling more than 126 million miles. 207 astronauts flew aboard the orbiter.

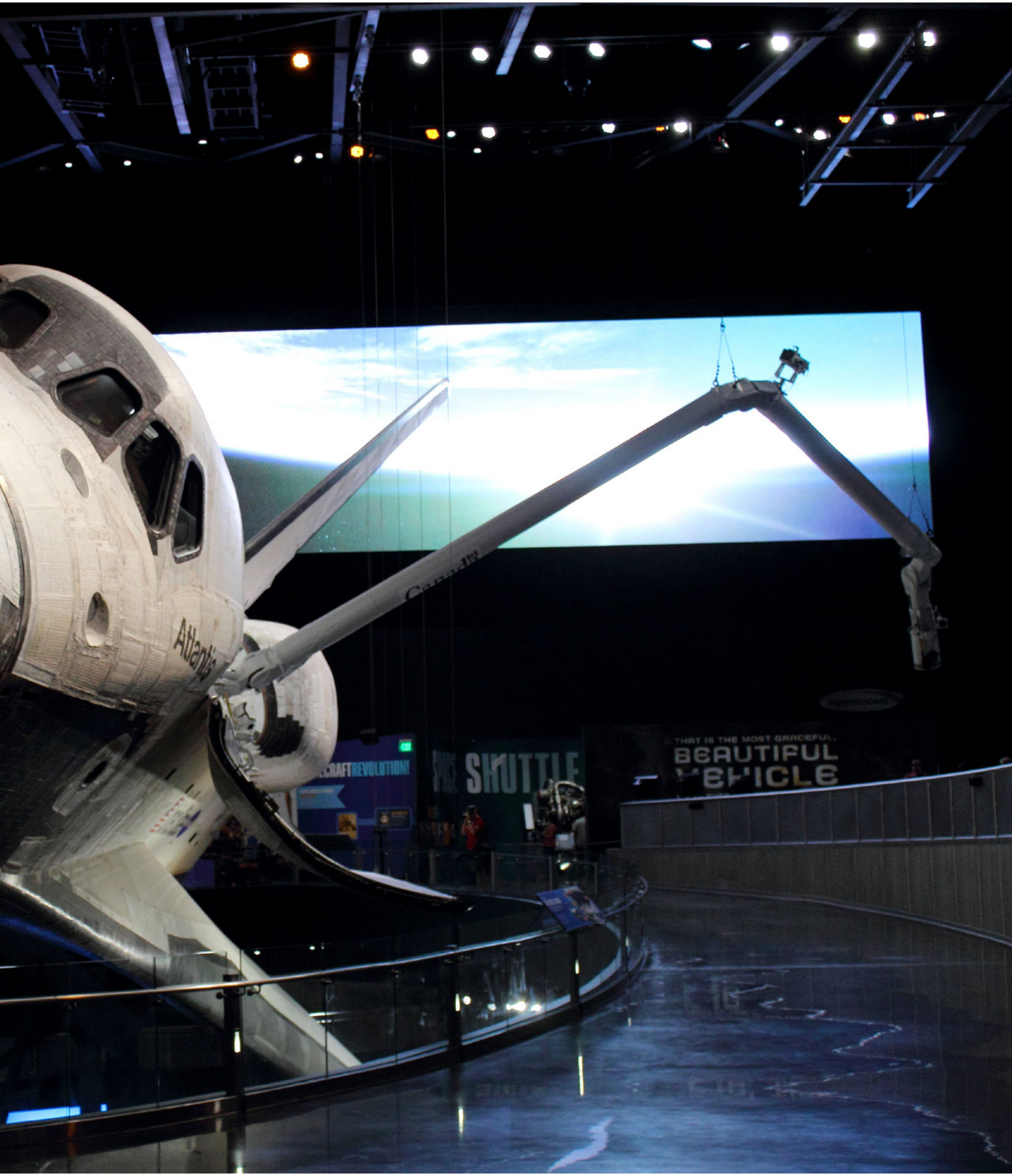
Also on the upper level are simulators that let you try your skills at spacewalking, cockpit mockups of the orbiter, and other interactive and static displays to entertain and educate visitors about the orbiter and the work it performed. There is also an actual Space Shuttle Main Engine on display in the far right corner near the back of the orbiter.

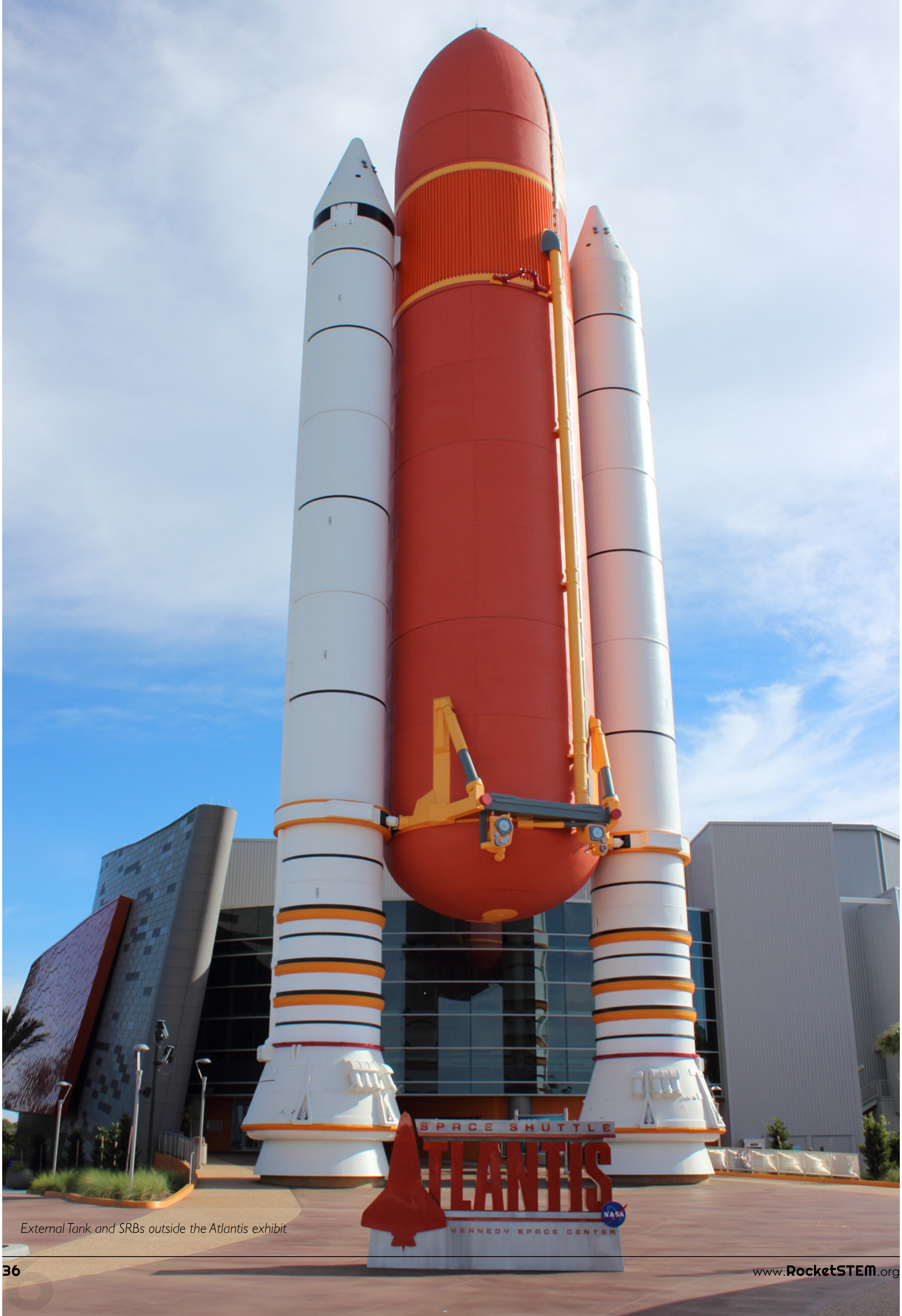
As you continue down a sloping ramp you get an up close view of the propulsion end of the orbiter and ultimately the belly of the orbiter and its sophisticated Thermal Protection Tile system. Take your time and marvel over the fact that this vehicle actually launched into space and returned 33 times over its lifetime. The 33 missions included deploying Satellites, performing Hubble Space Telescope servicing, and of course building of the International Space Station.

Speaking of the Hubble Space Telescope, inside the Atlantis facility there is a high fidelity replica of the telescope that is 43 feet long and 14 feet in diameter, that can be viewed

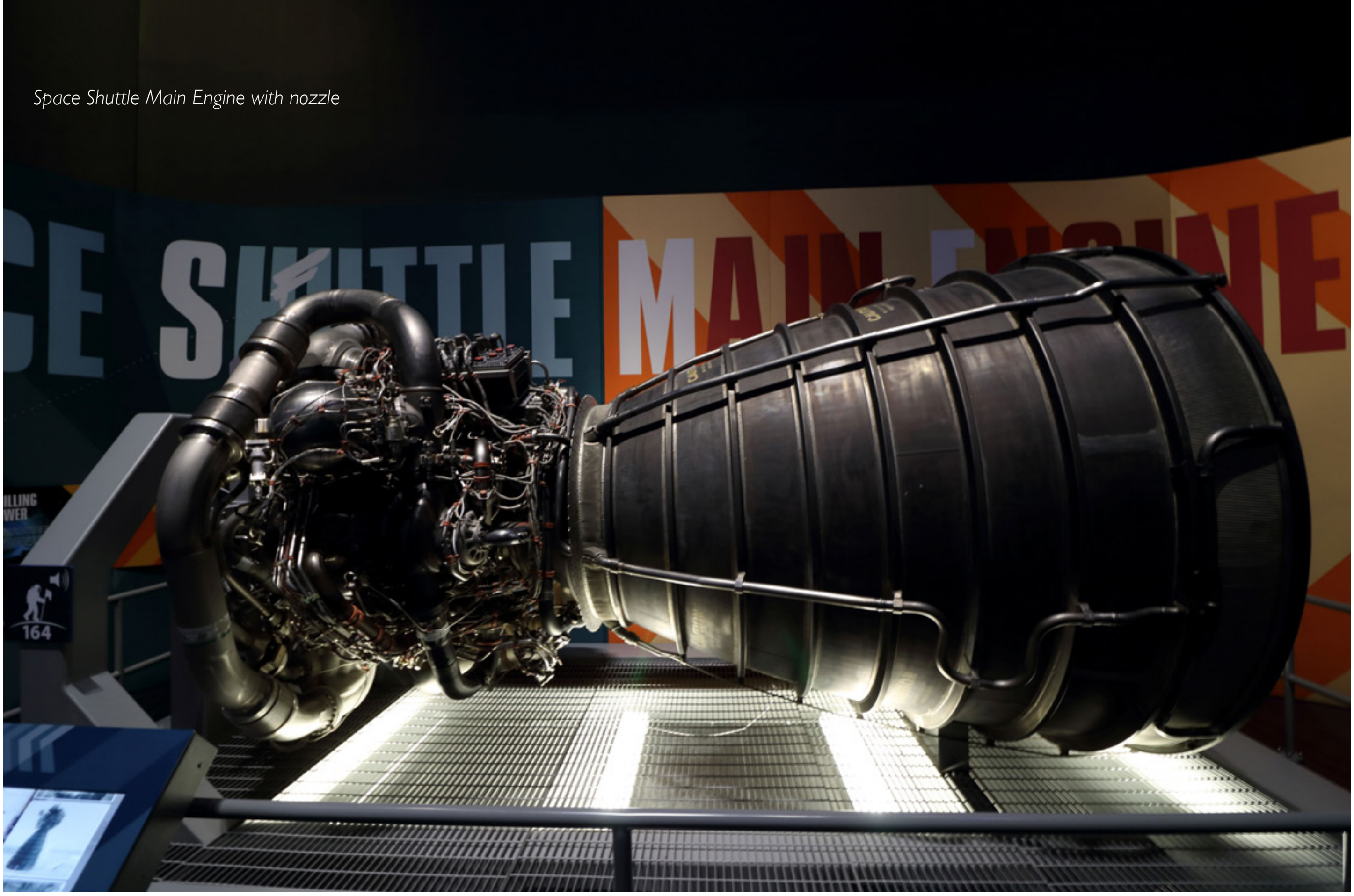


Space Shuttle Atlantis with the Canadarm extended.

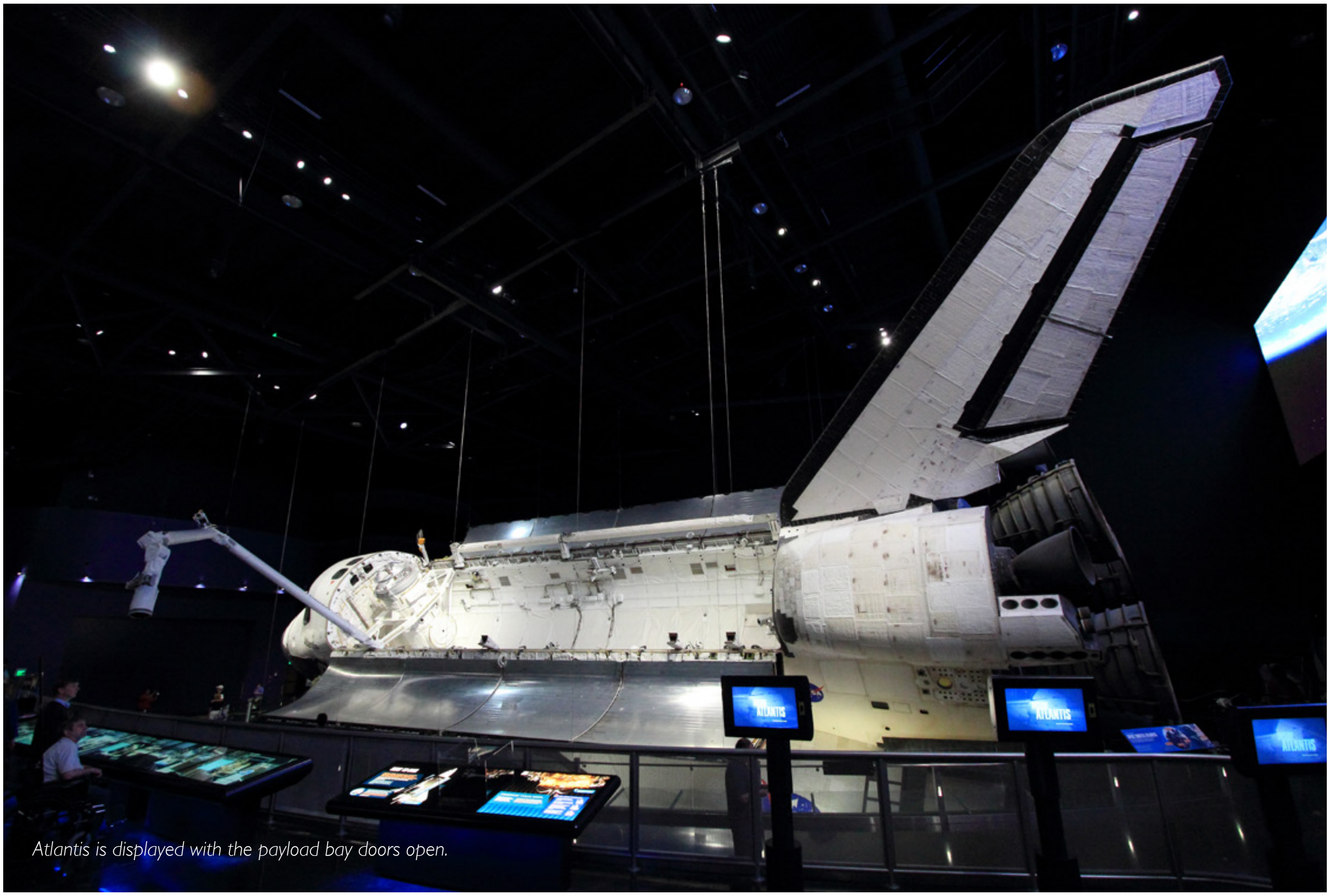

Atlantis
SHUTTLE
THAT IS THE MOST GRACEFUL,
BEAUTIFUL
VEHICLE



External Tank and SRBs outside the Atlantis exhibit



Space Shuttle Main Engine with nozzle



Atlantis is displayed with the payload bay doors open.

from the main floor just to the right of the door you exited the theater from, and again from the lower level. On the lower level you'll find another theater showing highlights of Hubble from its launch in 1990, through its repair missions, and of course showcasing some of the incredible images the telescope has provided to us all.

Also on the lower level you'll find high fidelity replicas of an International Space Station module, a space toilet, tires from Atlantis that actually were used in the final landing of STS-135, and much more. There's also the actual Beanie Cap from launch pad 39-B. The Beanie Cap, also known as the External Tank (ET) Gaseous Oxygen Vent Arm was used to keep oxygen venting from the External tank from condensing water vapor surrounding that area into water and possibly forming ice

FACTLET

Space Shuttle Atlantis is named for a sailing ship that operated out of the Woods Hole Oceanographic Institute in Massachusetts.

which could damage the orbiter. The center has actually made an interactive game below the beanie cap, check it out.

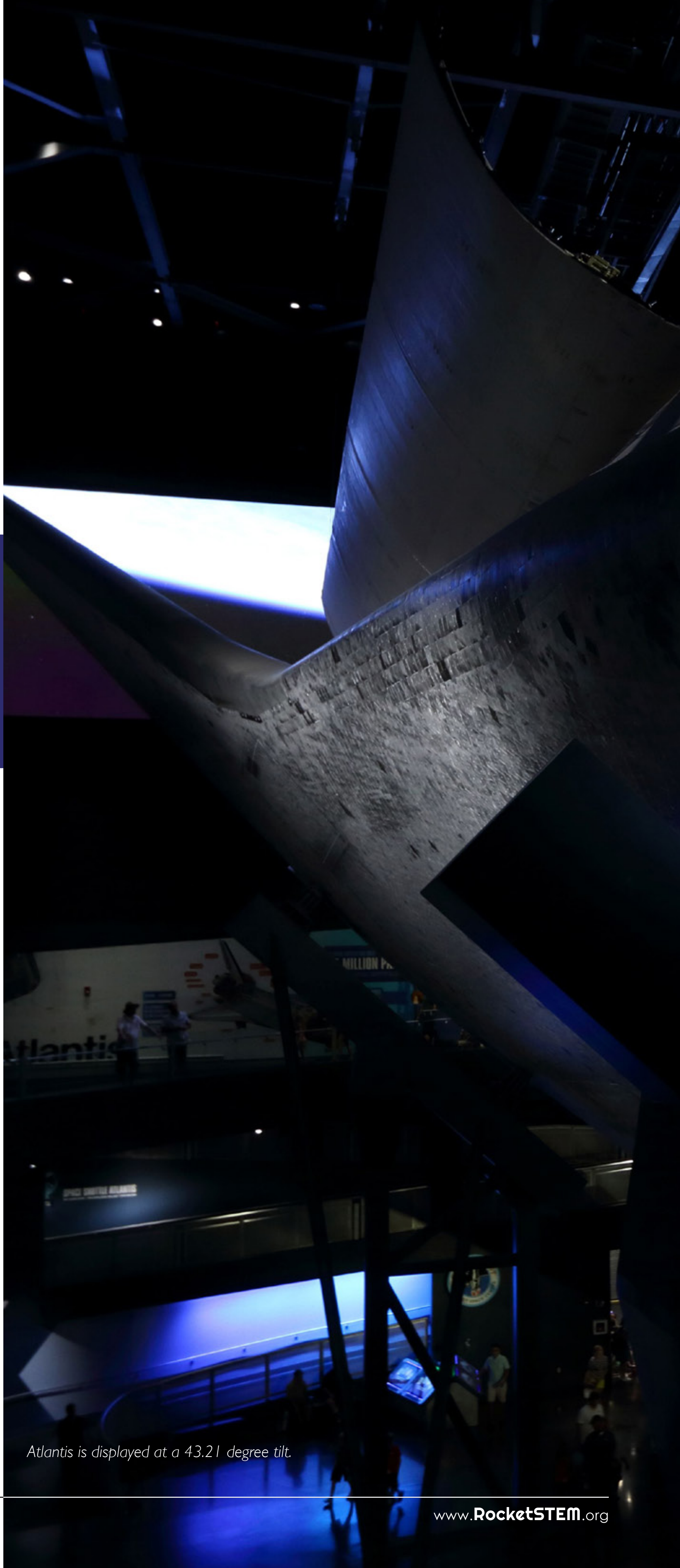
Don't forget to check out the Shuttle Launch Experience where you can find out what it feels, looks, and sounds like to launch aboard a space shuttle!

Also near the entrance to the gift shop you'll find more simulators where you can manipulate the robotic CanadaArm to perform specified tasks, or land the orbiter on the Shuttle Landing Facility.

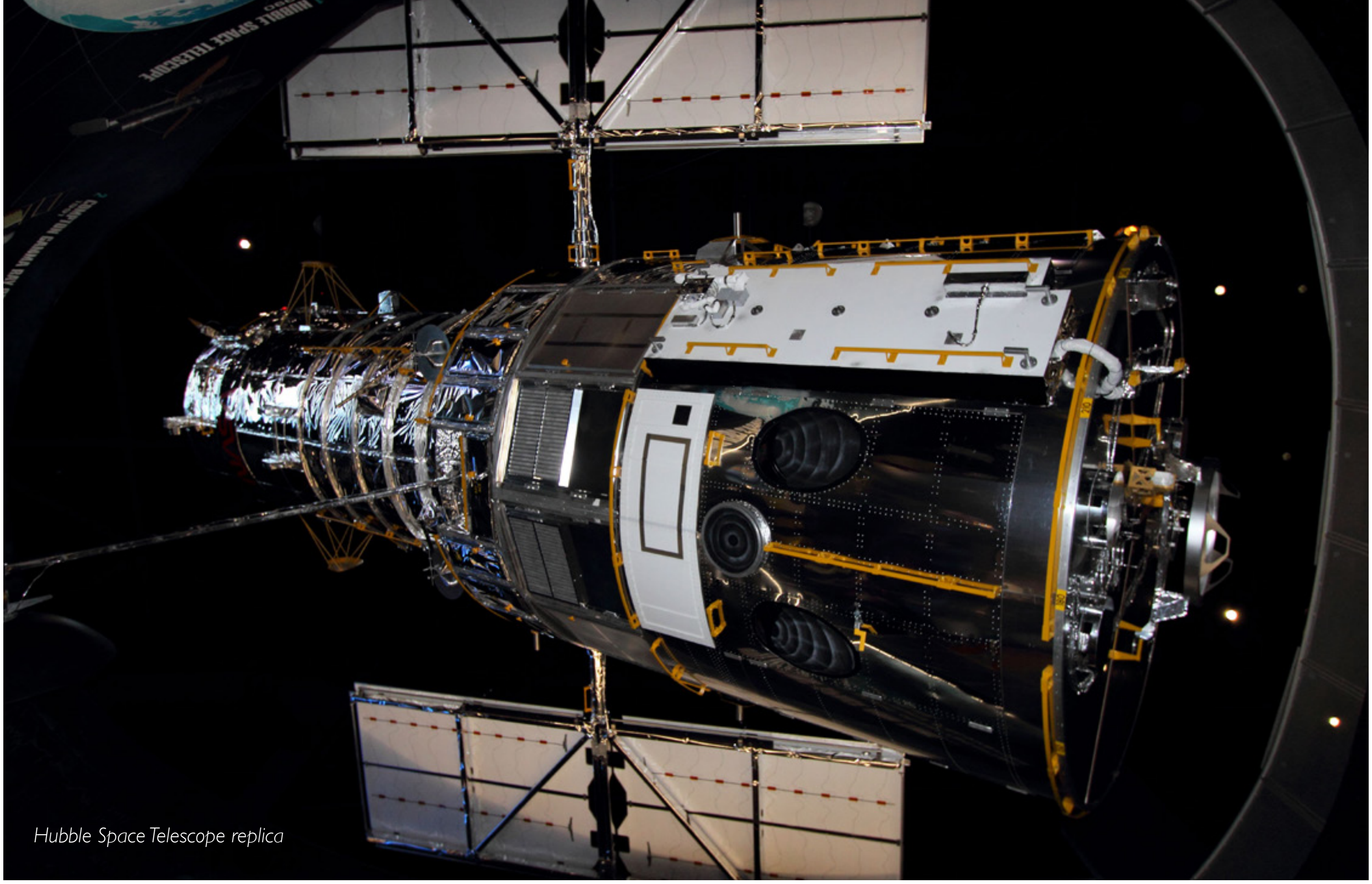
In all the facility contains over 60 interactive experiences, numerous static displays, and of course Atlantis which you can see from almost any angle you can think of. From casual tourists right up to true space geeks, everyone can find plenty to do and see at the Atlantis exhibit.

There are many more things to see and experience at the Kennedy Space Center, I only touched on some of the more prominent displays and experiences from my visits, be sure to allow yourself plenty of time to take in all the center has to offer and to see just a bit of what NASA has accomplished so far, and a peek at what is yet to come.

All photos taken by Lloyd Campbell.



Atlantis is displayed at a 43.21 degree tilt.



Hubble Space Telescope replica

LC-39B Gaseous Oxygen Vent Arm and Hood, aka the "Beanie Cap."

Shuttle era spacesuit and EMU

Forever Remembered

By Lloyd Campbell

A new memorial area dubbed “Forever Remembered” features artifacts recovered from the wreckage of the Challenger and Columbia orbiters. Columbia’s cockpit window frames along with a section of Challenger’s fuselage stand alone in individual displays against a black background.

It’s an eerie sight to see these pieces displayed. They provide a stark reminder to all that spaceflight is very, very difficult and should never be treated as routine.

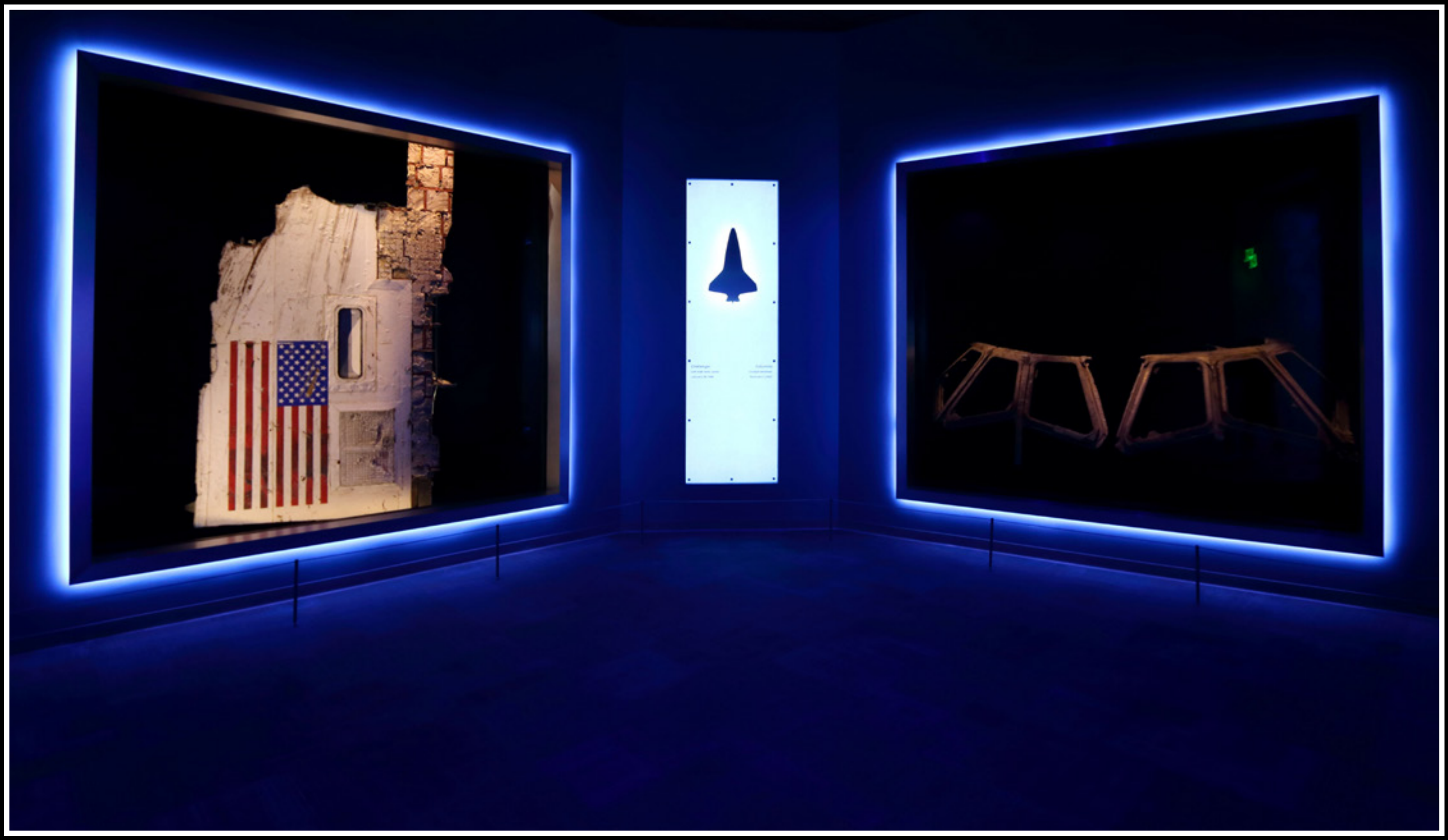
Encompassing nearly 2,000 square feet of area in the Atlantis building, the new space also contains an area honoring the 14 crew members who gave their lives in pursuit of their dreams.

Included in each crew member’s display is information about that crew member along with personal items from each of them. A few items among the personal items on display are Rick Husband’s cowboy boots, a research paper written by Judy Resnick, and a vintage Star Trek lunchbox that was owned by Michael Anderson. The families of the fallen astronauts loaned items to the KSC Visitors Complex for the display along with those provided by NASA.

The area also showcases the work that went into returning to flight after each of the accidents, including changes to the Shuttles, revised and new procedures for launch, new inspections both pre- and post-launch, and new processes for repairing the Shuttle on orbit in the event of foam strike damage during launch.

The new display is a fitting tribute to those brave souls who made the ultimate sacrifice while advancing our continued exploration of space. It provides not only a moving memorial of the lost Space Shuttles, but memorializes their crews for all time, while reminding us of the risk every astronaut and their families take every time they slip the surly bonds of Earth.

Displays line a wall with personal items for each crew member of the STS-51L mission lost aboard Challenger. Credit: Lloyd Campbell



Artifacts from Space Shuttles Challenger and Columbia. Credit: Lloyd Campbell

Displays line a wall with personal items for each crew member of the STS-107 mission lost aboard Columbia. Credit: Lloyd Campbell

Constructing a new ride

The newly assembled first liquid hydrogen tank, also called the qualification test article, for NASA's new Space Launch System rocket lies horizontally beside the Vertical Assembly Center robotic weld machine (blue) on July 22. It was lifted out of the welder after final welding was completed at NASA's Michoud Assembly Facility in New Orleans. Credit: Ken Kremer/www.kenkremer.com

NASA's deep space rocket takes shape in New Orleans

By Ken Kremer

NASA has finished welding together the very first fuel tank for America's humongous Space Launch System (SLS) deep space rocket currently under development. RocketSTEM had an up close look at the liquid hydrogen (LH_2) test tank shortly after its birth as well as the first flight tank, within hours of completion of the milestone assembly operation at NASA's Michoud rocket manufacturing facility located in New Orleans.

"We have just finished welding the first liquid hydrogen qualification tank article … and are in the middle of production welding of the first liquid hydrogen flight hardware tank [for EM-1] in the big Vertical Assembly Center welder," explained Patrick Whipps, NASA SLS Stages Element Manager during our tour of the massive factory.

"We are literally putting the SLS rocket hardware together here at last. All five elements to put the SLS stages together [at Michoud]."

This first fully welded SLS liquid hydrogen tank is known as a qualification test article. It was assembled using basically the same components and processing procedures as an actual flight tank, said Whipps.

"We just completed the liquid hydrogen qualification tank article and lifted it out of the welding machine and put it into some cradles. We will put it into a newly designed straddle carrier article next week to transport it around safely and reliably for further work."

Welding of the liquid hydrogen flight tank is moving along well.

"We will be complete with all SLS core stage flight tank welding in the VAC by the end of September," added Jackie Nesselroad, SLS Boeing manager at Michoud. "It's coming up very quickly!"

"The welding of the forward dome to barrel 1 on the liquid hydrogen flight tank is complete. And we are doing phased array ultrasonic testing right now."

44

SLS is the most powerful booster the world has even seen. Beginning in the 2020's it will propel NASA astronauts within the agency's Orion crew capsule on exciting missions of exploration to deep space destinations including potentially the Moon, asteroids and Mars - venturing further out than humans ever have before.

The LH_2 qualification test article was welded together using the world's largest welder – known as the Vertical Assembly Center, or VAC, at Michoud. The state-of-the-art welding giant stands 170 feet tall and 78 feet wide. It complements the world-class welding toolkit being used to assemble various pieces of the SLS core stage including the domes, rings and barrels that have been previously manufactured.

The fuel tank is a giant - measuring approximately 130-feet in length and 27.6 feet (8.4 m) in diameter.

The qual test article is the immediate precursor to the actual first LH_2 flight tank now being welded.

Technicians assembled the LH_2 tank by feeding the individual metallic components into NASA's gigantic 'Welding Wonder' machine - as it's affectionately known - at Michoud, thus creating a rigid 13 story tall structure.

The team was also already hard at work fabricating the first liquid hydrogen flight article tank in the VAC, right beside the qualification tank resting on the floor.

Welding of the other big fuel tank, the liquid oxygen (LOX) qualification and flight article tanks will follow quickly inside the impressive 'Welding Wonder' machine, Nesselroad explained.

The LH_2 and LOX tanks sit on top of one another inside the SLS outer skin.

The Vertical Weld Center tool used to fabricate barrel segments for the SLS liquid hydrogen and oxygen core stage tanks via vertical friction stir welding operations at NASA's Michoud Assembly Facility in New Orleans. To the right of the welder is the weld confidence barrell. Credit: Chase Clark

Two fuel tank domes were recently finished for the SLS rocket. One is a qualification article and the other is the actual flight article for the first mission (EM-1) set to launch in 2018. Credit: Chase Clark

The SLS core stage - or first stage - is mostly comprised of the liquid hydrogen and liquid oxygen cryogenic fuel storage tanks which store the rocket propellants at super chilled temperatures. Boeing is the prime contractor for the SLS core stage.

To prove that the new welding machines would work as designed, NASA opted "for a three stage assembly philosophy.

Whipps stated that engineers first "welded confidence articles for each of the tank sections" to prove out the welding techniques "and establish a learning curve for the team and test out the software and new weld tools. We learned a lot from the weld confidence articles."

"On the heels of that followed the qualification weld articles" for tank loads testing. "The qualification articles are as 'flight-like' as we can get them. With the expectation that there are still some tweaks coming."

"And finally that leads into our flight hardware production welding and manufacturing the actual flight unit tanks for launches."

"All the confidence articles and the LH_2 qualification article are complete."

What's the next step for the LH_2 tank?

The test article tank will be outfitted with special sensors and simulators attached to each end to record reams of important engineering data, thereby extending it to about 185 feet in length.

Thereafter it will loaded onto the Pegasus barge and shipped to NASA's Marshall Space Flight Center in Huntsville, Alabama, for structural loads testing on one of the new test stands currently under construction. The tests are done to prove that the tanks can withstand the extreme stresses and safely carry astronauts to space.

"We are manufacturing the simulators for each of the SLS elements now for destructive tests - for shipment to Marshall. It will test all the stress modes, and finally to failure to see the process margins," explained Whipps

The SLS core stage builds on heritage from NASA's Space Shuttle Program and is based on the Shuttle's External Tank (ET). All 135 ET flight units were built at Michoud during the 30 year Shuttle program by Lockheed Martin.

"We saved billions of dollars and years of development effort vs. starting from a clean sheet of paper design, by taking aspects of the Shuttle … and created an External Tank type generic structure – with the forward avionics on top and the complex engine section with four engines on the bottom," Whipps elaborated.

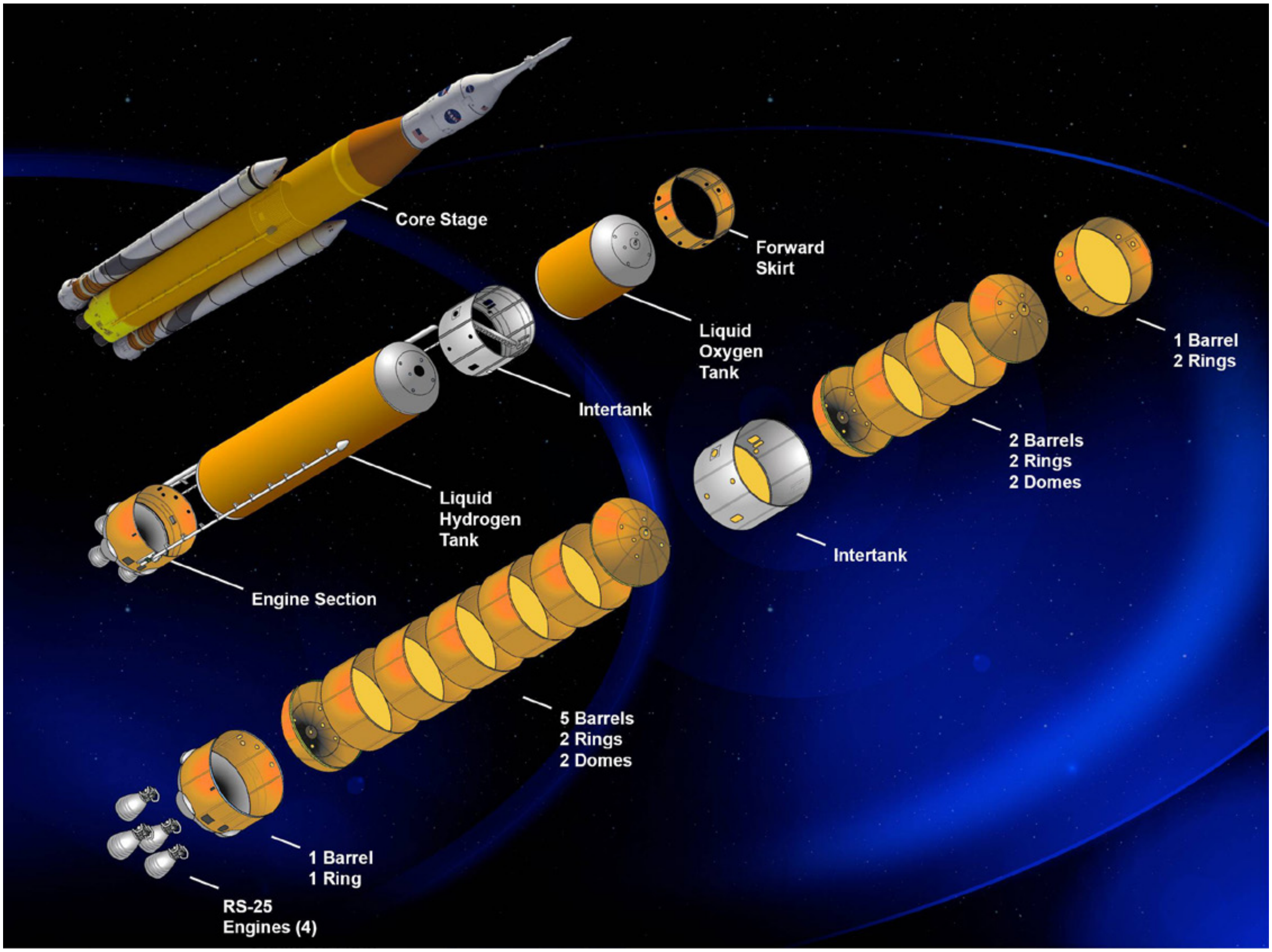
"This is truly an engineering marvel like the External Tank was – with its strength that it had and carrying the weight that it did. If you made our ET the equivalent of a Coke can, our thickness was about 1/5 of a Coke can."

"It's a tremendous engineering job. But the ullage pressures in the LOX and LH_2 tanks are significantly more and the systems running down the side of the SLS tank are much more sophisticated. Its all significantly more complex with the feed lines than what we did for the ET. But we brought forward the aspects and designs that let us save time and money and that we knew were effective and reliable."

The SLS core stage is comprised of five major structures: the forward skirt, the liquid oxygen tank (LOX), the intertank, the liquid hydrogen tank (LH_2) and the engine section.

The LH_2 and LOX tanks feed the cryogenic propellants into the first stage engine propulsion section which is powered by a quartet of RS-25 engines – modified Space Shuttle main engines (SSMEs) – and a pair of enhanced five segment solid rocket boosters (SRBs) also derived from the Shuttles four segment boosters.

The tanks are assembled by joining previously manufactured dome, ring and barrel



Graphic shows all the dome, barrel, ring and engine components used to assemble the five major structures of the core stage of NASA's Space Launch System (SLS) rocket in Block 1 configuration. Credits: NASA/MSFC

The Gore Weld Tool (foreground) and Circumferential Dome Weld Tool (background) used to fabricate dome segments for the SLS liquid hydrogen and oxygen core stage tanks via vertical friction stir welding operations at NASA's Michoud Assembly Facility in New Orleans. Credit: Ken Kremer

components together in the Vertical Assembly Center by a process known as friction stir welding. The rings connect and provide stiffness between the domes and barrels.

The LH_2 tank is the largest major part of the SLS core stage. It holds 537,000 gallons of super chilled liquid hydrogen. It is comprised of five barrels, two domes, and two rings.

The LOX tank holds 196,000 pounds of liquid oxygen. It is assembled from two barrels, two domes, and two rings and measures over 50 feet long.

The material of construction of the tanks has changed compared to the ET.

"The tanks are constructed of a material called aluminum 2219 alloy," said Whipps. "It's a ubiquitously used aerospace alloy with some copper but no lithium, unlike the Shuttle superlightweight ET tanks. This alloy is heavier but does not affect our payload potential."

"The intertanks are the only non welded structure. They are bolted together and we are manufacturing them also. It's much heavier and thicker."

The entire SLS core stage will tower more than 212 feet (64.6 meters) tall and sport a diameter of 27.6 feet (8.4 m).

The total weight of the empty core stage will be 188,000 pounds, and 2.3 million pounds when fully loaded with propellant. The empty ET weighed some 55,000 pounds.

Considering that the entire Shuttle ET was 154-feet long, the 130-foot long LH_2 tank alone isn't much smaller and gives perspective on just how big it really is as the largest rocket fuel tank ever built.

Every fuel tank welded together from now on after this series of confidence and qualification LOX and LH_2 tanks will be actual flight article tanks for SLS launches.

What's ahead for the SLS-2 core stage?

"We start building the second SLS flight tanks in October of this year," Nesselroad stated.

The maiden test flight of the SLS/Orion is targeted for November 2018 and will be configured in its initial 70-metric-ton (77-ton) Block 1 configuration with a liftoff thrust of 8.4 million pounds – more powerful than the Saturn V moon rocket.

Although the EM-1 flight in 2018 will be uncrewed, NASA plans to launch astronauts on the EM-2 mission slated for between 2021 and 2023.

The exact launch dates fully depend on the budget NASA receives from Congress, who is elected President in the upcoming election, and whether they modify NASA's objectives.

"If we can keep our focus and keep delivering, and deliver to the schedules, the budgets and the promise of what we've got, I think we've got a very capable vision that actually moves the nation very far forward in moving human presence into space," said William Gerstenmaier, associate administrator for the Human Exploration and Operations Mission Directorate at NASA Headquarters in Washington.

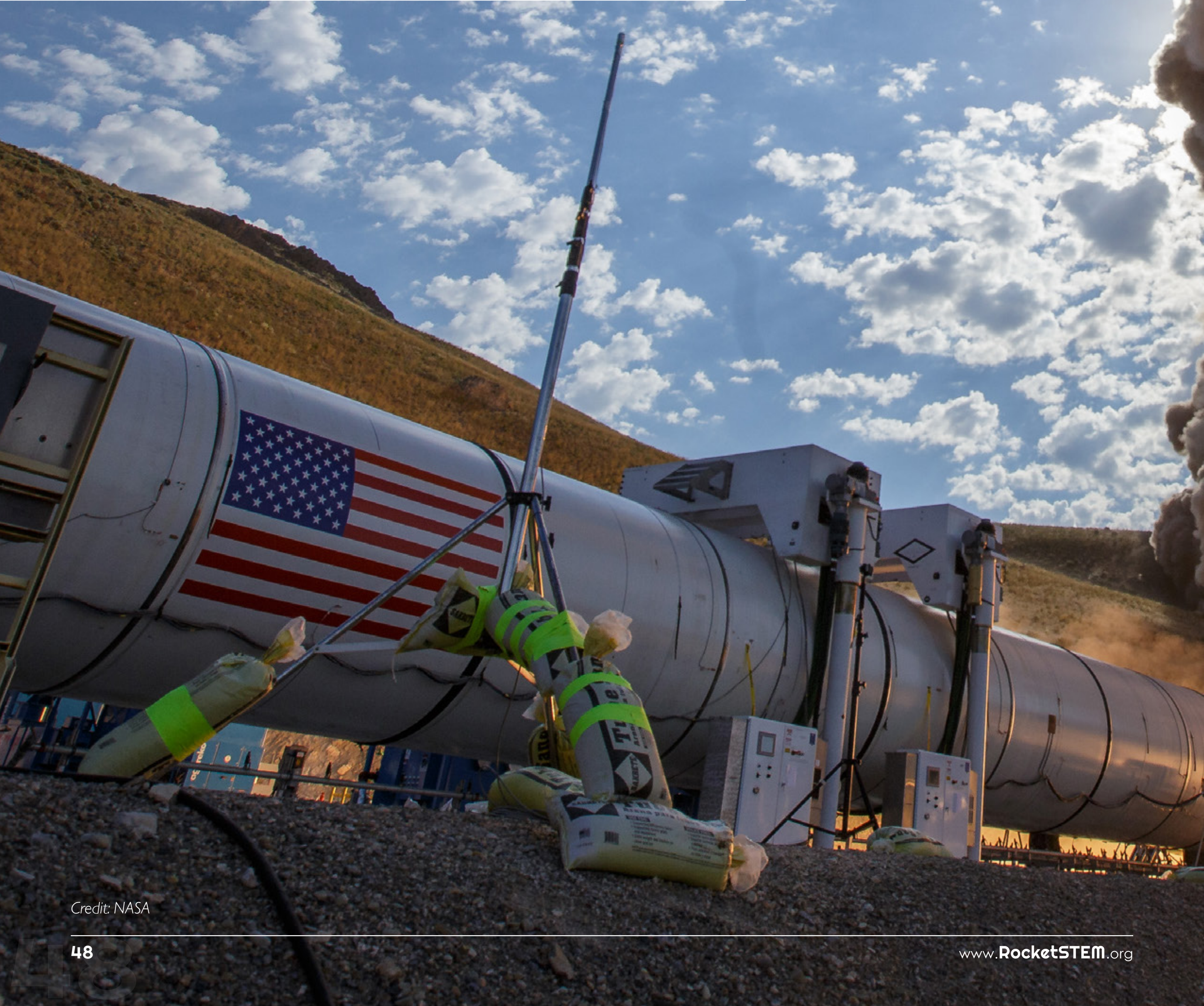
"This is a very capable system. It's not built for just one or two flights. It is actually built for multiple decades of use that will enable us to eventually allow humans to go to Mars in the 2030s."

NASA's SLS booster passes major milestone

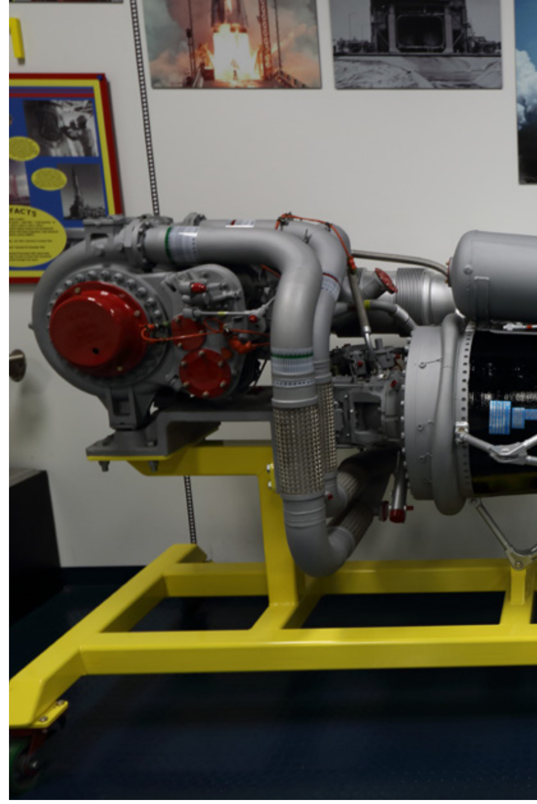
A booster for the most powerful rocket in the world, NASA's Space Launch System (SLS), successfully fired up on June 28 for its second qualification ground test at Orbital ATK's test facilities in Promontory, Utah. This was the last full-scale test for the booster before SLS's first uncrewed test flight in late 2018.

"This final qualification test of the booster system shows real progress in the development of the Space Launch System," said William Gerstenmaier, associate administrator for the Human Exploration and Operations Mission Directorate at NASA. "Seeing this test today, and experiencing the sound and feel of approximately 3.6 million pounds of thrust, helps us appreciate the progress we're making to advance human exploration and open new frontiers for science and technology missions."

The booster was tested at a cold motor conditioning target of 40 degrees Fahrenheit. When ignited, temperatures inside the booster reached nearly 6,000 degrees. The two-minute, full-duration ground qualification test provided NASA with critical data, captured by more than 530 instrumentation channels on the booster.



Credit: NASA



Among the artifacts on display at the Air Force Space and Missile History Center are an original Gemini console (top left), an Atlas sustainer rocket engine (top roght), and a Jupiter rocket nose cone (white cone in bottom photo). Credit: Lloyd Campbell

Air Force museum bringing history of rocketry to life

By Lloyd Campbell

The Air Force Space & Missile Museum and separate History Center located in Cape Canaveral, Florida, provide a unique look back at past space adventures, hardware, and facilities. You'll find the entrance to the History Center just outside the main entrance of the Cape Canaveral Air Force Station.

The History Center, located just off the parking lot provides visitors with information regarding each of the cape's pads, both retired and active, including what type of vehicles launched from them, what missions, and other fun facts about each complex. Admission to the History Center is free.

There is a lot of history represented in the center. Many important unmanned launches occurred at Cape Canaveral Air Force Station, including the launch of the first American satellite, Explorer 1 on January 31st, 1958 from Launch Complex 26. All the manned Mercury missions launched from Cape Canaveral with the two sub-orbital flights launching from Launch Complex 5/6 and the four orbital flights launching from Launch Complex 14. In addition, all 10 manned Gemini missions launched from Launch Complex 19 at Cape Canaveral. Finally, Apollo 7 launched from Launch Complex 34 on the first manned Apollo flight.

Currently in use are Launch Complexes 37, 40, and 41 and information about those facilities and the vehicles currently launching from them is also available in the history center.

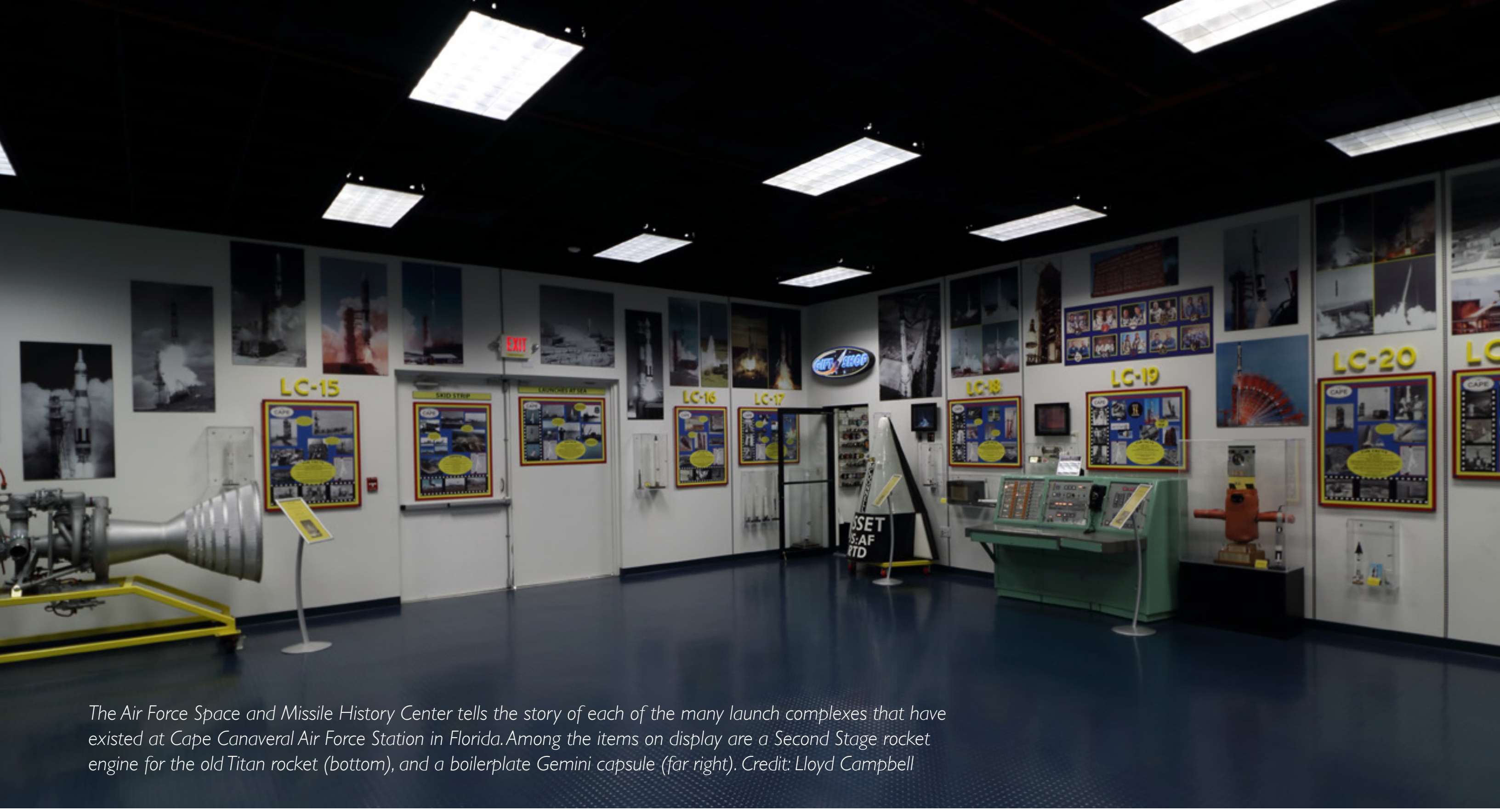
Also located in the History Center you'll find numerous artifacts including an Atlas rocket booster engine built by Rocketdyne, a Minuteman Reentry vehicle, a Jupiter nosecone, a Titan I second stage rocket engine, a Mercury Capsule boilerplate, a Launch Complex 19 Titan test console and many more interesting artifacts.

You'll normally find one of the dedicated volunteers there who will be happy to answer any questions you may have about the museum or its artifacts.

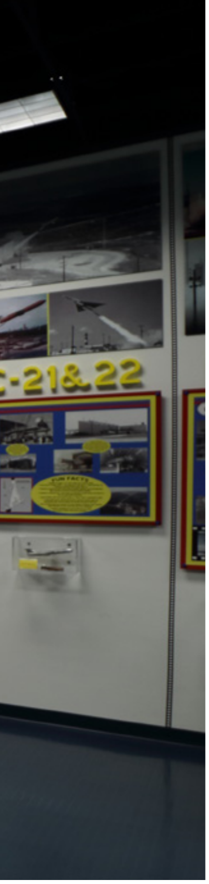
Don't forget to check out the gift shop!

Another part of the Air Force Space and Missile Museum is located within the confines of Cape Canaveral Air Force Station. This includes the museum itself and a number of the launch pads used in the early days of space exploration. The Air Force used to provide a tour to those areas once a week, unfortunately the budget sequestration of 2013 cut the funding for that tour and it was never restored.

However you can still see those other areas, and more via an add-on tour available from the Kennedy Space Center Visitor



The Air Force Space and Missile History Center tells the story of each of the many launch complexes that have existed at Cape Canaveral Air Force Station in Florida. Among the items on display are a Second Stage rocket engine for the old Titan rocket (bottom), and a boilerplate Gemini capsule (far right). Credit: Lloyd Campbell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Complex. Called the "Up Close Cape Canaveral: Then and Now Tour," the bus tour is currently only offered Thursdays through Sundays at 12:20 p.m. Due to security requirements of the base, all participants must provide a valid form of identification, for American citizens, a U.S. government-issued Driver's License or U.S. State ID card is required for all tour participants age 18 and over, and International adult and child participants must present a valid passport to take the tour.

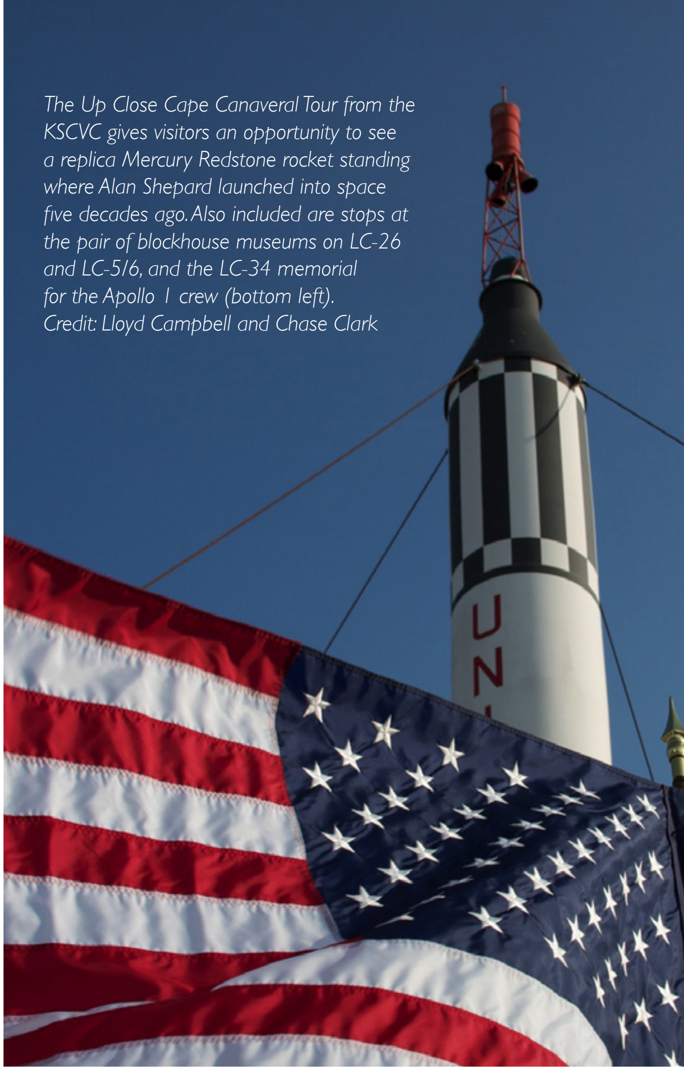
On this tour you'll see the museum's Rocket Garden where you'll find numerous launch vehicles including a Delta IV Common Booster Core, like the three used recently in the Delta IV Heavy NROL-37 launch. Also you'll find a Minuteman I missile, a Firebee II target drone, a Titan I Intercontinental Ballistic Missile, a Corporal surface-to-surface guided missile, a Polaris A3 Fleet Ballistic Missile, and oddly enough, a railroad engine. The locomotive was once used to transport Titan missiles. You'll discover other unique vehicles and artifacts in the Rocket Garden.

You'll also see Launch Complex 26. There you will find the blockhouse, gantry, and pads located just off the rocket garden. This complex launched the first American satellite, Explorer 1 on January 31st, 1958. The blockhouse which sits a short 400 feet from the two pads has walls that are two feet in depth, windows comprised of 45 layers of glass totaling out at approximately one foot in thickness, and specially armored blast doors, all to protect the launch personnel working inside from any explosion occurring just outside their secure work area. The launch gantry towers 111 feet above the ground and was used for assembling and servicing launch vehicles at the complex.

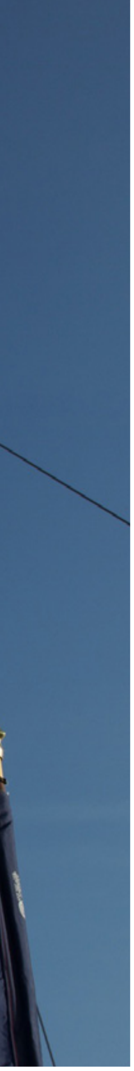
Adjacent to Complex 26, you'll find Launch Complex 5/6 where the first Americans to launch into space began their journeys. The first two Mercury program flights lifted off from Launch Pad 5 of the complex, Alan Shepard and Gus Grissom were the brave astronauts who took those first two sub-orbital flights and you can stand right where they lifted off from. On Pad 5 there is even a full-size replica of a Mercury Redstone launch vehicle to give you the feeling of what it was like back in 1961. Be sure to check out the launch ring on Pad 6, it was all that held that Redstone vehicle upright before it lifted off. Don't forget to check out the Blockhouse located at Complex 5/6 which contains much of the original equipment used to launch those early Mercury flights.

The tour also will take you to other parts of the base that are not part of the Air Force Space & Missile Museum, including Launch Complex 14 where John Glenn launched in his Friendship 7 Mercury Capsule on top of an Atlas rocket to become the first American to orbit the Earth. You will also see Launch Complex 19, where all of the manned Gemini Missions launched from. And you'll see Launch Complex 34 where the Apollo 1 crew, Gus Grissom, Ed White, and Roger Chaffee lost their lives when a fire broke out in their capsule on the pad during a routine test. While at LC-34 you may even witness a Delta IV rocket being prepared for launch at nearby Launch Complex 37. Another stop on the tour is the Cape Canaveral Lighthouse.

While visiting the Space Coast of Florida, take the time to head over to Cape Canaveral and check out the History Center and I highly recommend taking the "Up Close Cape Canaveral: Then and Now Tour" while visiting the Kennedy Space Center Visitor Complex to see other areas of the Cape Canaveral Air Force Station where space history was made.



The Up Close Cape Canaveral Tour from the KSCVC gives visitors an opportunity to see a replica Mercury Redstone rocket standing where Alan Shepard launched into space five decades ago. Also included are stops at the pair of blockhouse museums on LC-26 and LC-5/6, and the LC-34 memorial for the Apollo 1 crew (bottom left). Credit: Lloyd Campbell and Chase Clark

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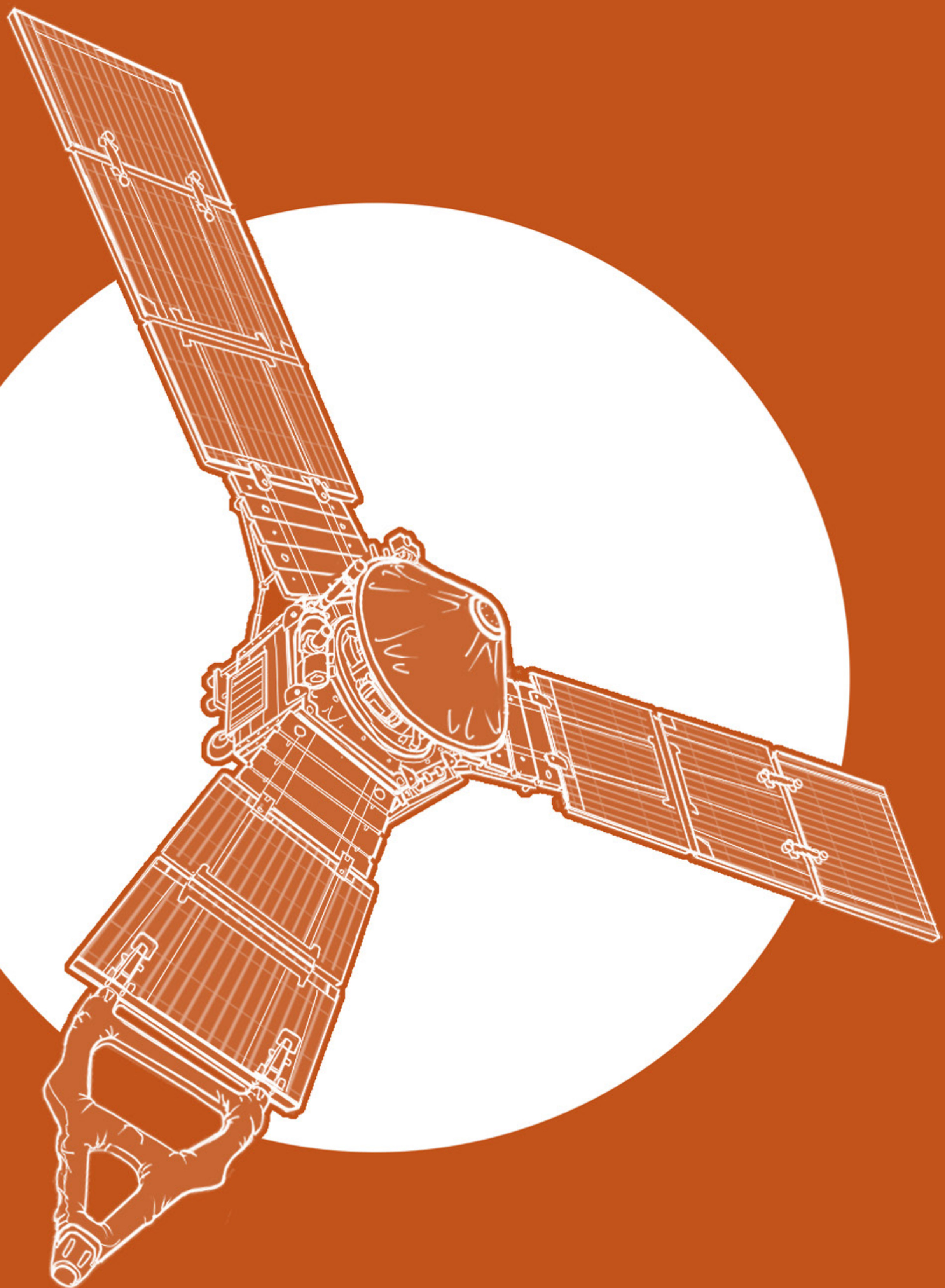


Artist illustration of the Juno spacecraft orbiting Jupiter. Credit: Sebastian Kings

JUNO

Unlocking Jupiter's secrets

By Lloyd Campbell

A spacecraft named Juno hopes to unlock more secrets about the largest planet in our solar system, Jupiter, by studying the planet from its core all the way out to its large magnetic field. The mission's objective is to help us better understand the origins of our solar system by studying how Jupiter formed.

Jupiter is comprised of mostly helium and hydrogen, similar to the Sun, so it is believed that it formed early in the creation of our solar system.

It is believed that beneath the dense clouds of Jupiter are clues that will give insights into how Jupiter and our solar system formed. Juno will be able to peer under those dense clouds that shroud Jupiter using its scientific instruments. How much water and ammonia does the planet have? Is there Oxygen present? Is there a solid core at the center of Jupiter, and if so, how large is it? Juno will examine Jupiter's magnetic field to determine how large it is, how it is generated, and how it affects the planet's auroras.

Under the massive clouds tops the hydrogen gas that is a great part of Jupiter's atmosphere is squeezed under immense pressure until it actually liquefies into metallic hydrogen. The theory is that this metallic hydrogen is the source of Jupiter's magnetic field and Juno will help determine if the theory is correct.

We should also get a good look at the planet's poles, up close, for the first time.

In addition to understanding our own solar system better, it is also hoped that a better knowledge of Jupiter will help us better understand distant planetary systems that are being discovered around distant stars.

The name Juno actually comes from Greek mythology. Jupiter was not the most faithful husband to his wife Juno, and thought that by surrounding himself with a veil of clouds he could hide from her. However Juno had the ability to peer through those clouds and see him. Much like the mythical Juno, the spacecraft will peer beyond those cloud tops to unlock the secrets Jupiter has been hiding from us.

Juno is not a very large spacecraft at all. The main body only measures 11.5 feet high by 11.5 feet in diameter. However when the three 29.5 foot long solar panels are extended, the span of the spacecraft is more than 66 feet. Juno weighs in at just 3,513 pounds but carries onboard an additional 2,821 pounds of fuel and 1,658 pounds of oxidizer, bringing its total weight at liftoff to 7,992 pounds. The spacecraft is designed to rotate during flight like many other previous probes. A rotating spacecraft makes pointing of the spacecraft much easier to control and stabilizes it.

Juno will encounter higher radiation levels around Jupiter than normally encountered in space; therefore its sensitive electronics needed a higher level of protection than ever before. A newly designed electronics vault was designed to protect the electronics. The vault is made of titanium; each side of the cube is nearly 9 square feet in area and approximately 1/3rd of an inch in thickness. The titanium cube weighs about 400 pounds and protects Juno's most sensitive and critical electronics.

Juno generates its power from three solar arrays of 33 solar panels and three MAG booms. It's the first solar-powered spacecraft designed to operate so far from the Sun.

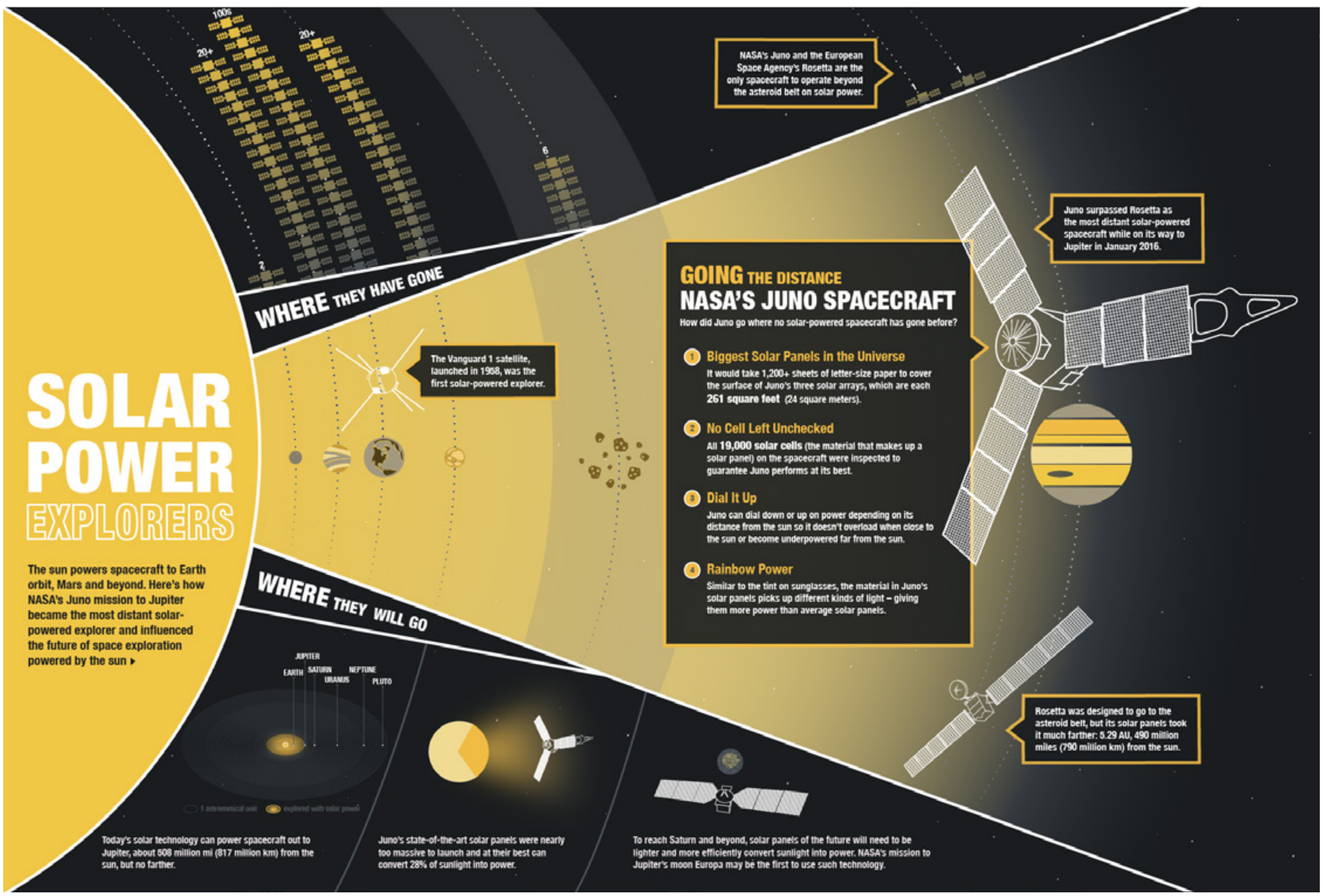
Sunlight reaching Jupiter is 25 times less than what reaches our Earth, therefore Juno's power generating panels had to be quite large. Solar panel technology has advanced considerably and Juno's panels are 50 percent more efficient than panels flown on spacecraft 20 years ago.

Total power generation from the panels is 14 kilowatts, or 14,000 watts, of electricity when Juno is near Earth, but when operating n Jupiter's neighborhood, they will only be able to produce about 400 watts. To put that into perspective, the toaster you make your toast in for breakfast uses at least 800 watts of power.

Juno is not a very power hungry spacecraft, so even with the low power output at Jupiter, solar panels were still a viable option for the spacecraft. Its electronics and instruments are very energy-efficient. Add in a mission that avoids Jupiter's shadow and solar power is completely possible. Once deployed following launch, Juno's panels remained, and will remain, in constant sunlight except for a few minutes during the Earth flyby. When Juno is in eclipse or not in line with the Sun, two 55 amp lithium-ion batteries keep the spacecraft operating until the panels take over.

Juno's science package consists of 29 different sensors feeding eight onboard instruments, (MAG, MWR, Gravity Science, Waves, JEDI, JADE, UVS, JIRAM), while a ninth instrument, the JunoCam is aboard to generate images for public and educational outreach.

The Microwave Radiometer (MWR) will investigate what's under those massive cloud tops enveloping Jupiter. It can supply scientists with data on the structure of Jupiter's atmosphere, its chemical composition, how it moves, and do all this down to a depth of approximately 342 miles (550 kilometers) below those cloud tops. The data should tell us how far



The sun powers spacecraft to Earth orbit, Mars and beyond. Here's how NASA's Juno mission to Jupiter became the most distant solar-powered explorer and influenced the future of space exploration powered by the sun. Credit: NASA/JPL-Caltech down those clouds extend from the top, including the Great Red Spot.

Comprised of six antennas, MWR will be able to determine how much water is contained within the planet's atmosphere. In order to 'see' what's under those cloud tops, MWR measures the microwave radiation being emitted from inside Jupiter.

Jupiter's strong radiation belt blocks any observation of the microwave radiation from Earth, but due to Juno's low altitude passes, MWR will be able to study them in detail. In order to study the layers under those cloud tops, MWR measures the different frequencies of microwave radiation, MWR can determine from what depth that specific frequency came from since the depth from which radiation can escape depends on frequency. MWR will operate during five of the 32 science orbits when Juno is oriented such that the MWR antennas view the planet directly below during the pass.

The Gravity Science (GRAV) experiment is designed to help scientists understand what lies beneath the dense clouds, if there's a dense core at Jupiter's center, what makes up the internal structure and how the material inside Jupiter flows. It will do this by mapping the planet's gravitational field. The GRAV will determine these things out by detecting subtle changes to Juno's orbit. The orbit will be changed due to variations in the underlying structure of Jupiter. As Juno gets closer to Jupiter, those changes are more easily detected by analyzing shifts in the frequency of a radio signal Juno transmits to Earth and receives back.

The Magnetometer Experiment (MAG) will create a three-dimensional map of Jupiter's entire magnetic field that goes all the way around the planet. Scientists using this map will be able to identify Jupiter's internal structure and how it generates the magnetic field from the constant churning of electrically charged material below the surface. It will also help in the study of Jupiter's auroras which are created from electrical currents, known as Birkeland currents, which align with the magnetic field and produce the auroras near Jupiter's poles.

This color view from NASA's Juno spacecraft is made from some of the first images taken by JunoCam after the spacecraft entered orbit around Jupiter on July 5. Credit: NASA/JPL-Caltech/SwRI/MSSS

Another instrument that will help study Jupiter's auroras is the Jupiter Energetic Particle Detector Instrument (JEDI). It will study the charged particles, electrons and ions, which travel around Jupiter. Those particles are influenced by Jupiter's magnetic field and JEDI will determine how much energy they carry, their type, and what direction they are buzzing around Jupiter.

Working closely with JEDI is the Jovian Auroral Distributions Experiment (JADE), another set of sensors examining the electrons and ions that produce Jupiter's auroras. Jade also will contribute to MAG's mapping of the Magnetosphere. While JEDI measures the high energy particle, JADE measures the low-energy particles.

Providing a different look at Jupiter's auroras is the Jovian Infrared Auroral Mapper (JIRAM). JIRAM will provide an infrared as well as a visual look at the auroras. The instruments can probe 30 to 45 miles into the atmosphere under the cloud tops and should be able to produce maps that will show the interaction between Jupiter's atmosphere and the magnetic field.

Working with JADE and JEDI is the Ultraviolet Imaging Spectrograph (UVS) which will image Jupiter's auroras in ultra-Violet light.

Juno also has an instrument simply referred to as Waves. Waves will measure radio and plasma waves contained in the magnetosphere. A relatively simple instrument, Waves is made up of two sensors, an electric dipole v-shaped antenna which will detect the electric component in the plasma and radio waves. The second sensor is a magnetic antenna, comprised of a small six-inch core with a fine wire wrapped around it 10,000 times. It detects magnetic fluctuations.

The last instrument on Juno is not really a science instrument, JunoCam is the spacecraft's color, visible light-camera designed to take images of Jupiter's cloud tops. While the wide angle view will help provide context for the spacecraft's other

This Atlas V 551 rocket launched Juno into space on August 5, 2011. Credit: United Launch Alliance

The JunoCam consists of a camera head and an electronics box, which is housed inside the spacecraft's protective radiation vault). In the inset image, JunoCam is shown mounted on the orbiter. Credits: NASA / JPL-Caltech

instruments, JunoCam's primary purpose is for public engagement. Images taken by the JunoCam will be available to the public via the Juno mission website. Images will be taken mainly while the spacecraft is making its close flybys of the planet, about 3,100 miles above the cloud tops.

Remember that Juno is spinning at two revolutions per minute at that point, so images would be blurred if JunoCam took a full image like you do with your DSLR. To solve this issue, JunoCam takes thin strips of an image at the same rate that the spacecraft is spinning, then stitches them together to complete a full image.

The camera is mounted on the outside of Juno exposing it to the high-energy particles that surround Jupiter, therefore eventually it will be so damaged by the particles that the team will just shut it down for the remainder of the mission. They expect it to last at least seven orbits, plenty of time for some great imagery to be returned to Earth.

Just a few days after Juno entered orbit on July 5, Junocam was already operating. The first high resolution images won't be taken until August 27, however it did send down a grainier image indicating that Juno survived its first pass through Jupiter's extreme radiation.

The JunoCam team also has a website where you can talk about the images. You can also vote on points of interest for JunoCam to photograph on upcoming orbit(s). You can also download and process images and then upload them back to the website and see other people's processed images. Go to https://www.missionjuno.swri.edu/junocam to explore JunoCam community on your own.

Juno's long journey to the gas giant began over five years before its arrival in the Jovian system. Launching on August 5, 2011 on top of an United Launch Alliance Atlas V rocket from cape Canaveral Air Station. The Atlas V is a powerful rocket on its own, but to get Juno to Jupiter, five Solid Rocket Boosters were added to the launch vehicle to provide more thrust to lift the 7,992 pound (3,625 KG) probe away from the Earth.

The trajectory of the spacecraft initially placed it in a heliocentric orbit that took it out past the orbit of Mars before maneuvering to a gravity assist flyby of Earth over two years after launch. On October 9, 2013 Juno skimmed passed the Earth, zipping past us just 310 miles above the surface while gaining speed along the way. The Earth flyby resulted in an increase of 16,330 miles per hour to the spacecraft's velocity. The probe then shot out of Earth's gravity heading on a direct path to Jupiter.

Getting to Jupiter is no easy task, getting into orbit is even harder. After nearly five years of flight and over 1.7 billion miles travelled, the spacecraft would be approaching Jupiter at an astonishing speed. Juno would have the title of the fastest spacecraft ever with a top speed of over 165,000 mph and would be approaching Jupiter at over 150,000 mph as the giant planet's gravity pulled it in.

If the burn to slow it down to enter orbit failed, it would just scream past Jupiter and keep right on going. However the 30 minute long orbit entry burn did go off as scheduled, and while it only slowed the spacecraft down 1,212 mph, that was all that was needed to put Juno in what is known as its capture orbit.

The first two orbits, called 'Capture Orbit.' will each take 53.5 days to complete and are used primarily as a way to save fuel as the gravity of Jupiter continues to slow the spacecraft down during these orbits allowing it to get into its planned 14 day orbit of the planet.

During this first orbit the science team will check out all the instruments and begin taking some science measurements to ensure all is functioning well with the spacecraft in the Jupiter environment. The Capture Orbit phase of the mission will not complete until October 14.

Five days after the Capture Orbit phase of the mission comes what is called the Period Reduction Maneuver. This involves another burn of the engine designed to bring the spacecraft's 53.5 day orbit around Jupiter down to just 14 days. This time the burn will last for 22 minutes and is the last planned large firing of the spacecraft's main engine.

Due to some unique conditions associated with the maneuver, the spacecraft will have three active science instruments during this phase of this mission. The spacecraft will be at a unique rate of spin and altitude during this phase which should allow the Microwave Radiometer to scan

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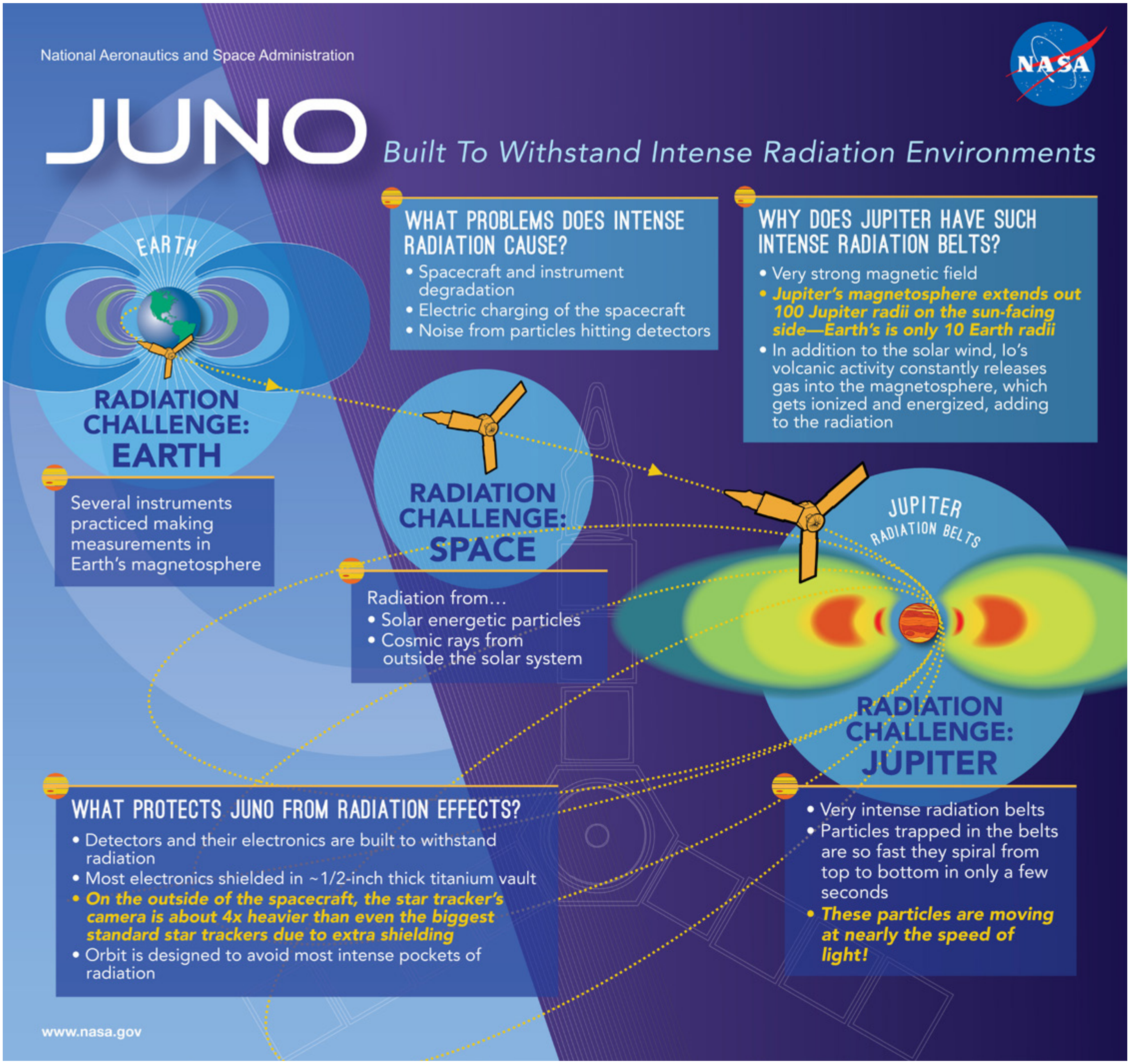


Juno launched for Jupiter in 2011 to study the gas giant's atmosphere, aurora, gravity and magnetic field. This infographic illustrates the radiation environments Juno has traveled through on its journey near Earth and in interplanetary space. All of space is filled with particles, and when these particles move at high speeds, they're called radiation. With its insertion into orbit around Jupiter, Juno will now study one of the most intense radiation environments in the solar system. Credit: NASA/JPL-Caltech

across Jupiter's longitudes at a high rate. The Advanced Stellar Compass will image Jupiter's north polar region and darkened atmosphere, while the Flux Gate Magnetometer will gather additional data that may be useful later to fill in potential gaps in the global magnetic field mapping that will occur during the science orbits.

Orbits 4 to 36, also known as the Science Orbits, are where the bulk of the science collection will occur. On each pass of the planet, as the spacecraft comes closest to Jupiter, it will make small adjustments to its speed, each less than 18 MPH, to ensure that on the next orbit, the longitudinal track for the closest encounter with Jupiter is where it should be.

Each Science orbit will not necessarily fly the same spacecraft orientation as the previous orbit. The reason behind this is to highlight a specific science instrument on that orbit, sometimes it will be the Microwave Radiometer (MWR), sometimes the Gravity Science Experiment (GRAV), it all depends on what science data is predetermined to be the highest priority gathered on the upcoming orbit.

Even on orbits not oriented to be a specific instrument's 'prime' orbit, at least some of the other science packages will still operate. For example on a MWR orbit, the spacecraft spin axis is oriented to get the best view of the planet directly below, so the JunoCam and the Infrared

Imager/Spectrometer will be collecting their nest data on that orbit, but the Gravity Science experiment will still be operating during that orbit, but with only the X-Band instrument collecting data, the Ka-Band translator (Kat) is off since it requires the spacecraft to be oriented towards Earth. Then on a GRAV oriented orbit, when the spacecraft is oriented towards Earth, the Kat can download data to Earth in real-time, but the orientation reduces the amount of data collected by other instruments.

The design of the orbits should allow Juno to cover the entire planet with its instruments, giving scientists a good picture of all of Jupiter from their various instruments.

The largest of Juno's six MWR antennas (shown here) takes up a full side of the spacecraft. Credit: NASA

In order to avoid the highest levels of radiation coming from Jupiter's radiation belts, while still getting the spacecraft very close to the planet to allow the science package to complete the assigned tasks, Juno's scientists have designed the orbits to be highly elliptical.

The spacecraft approaches the gas giant from the north, zipping down over the north polar region of the planet coming in as close as 2600 miles, then comes out from the southern polar region and heads out away from the planet before curving back for another pass.

While each science orbit lasts nearly 14 days, most of the instrument observations are taken while Juno passes closest to Jupiter. These close passes are from pole to pole as Juno is flying a polar orbit, and the closest encounters only last around two hours since Juno is still travelling at a very fast velocity, although the instruments are still collecting data during the approach and departure also.

The final phase of the mission is called the Deorbit phase. Designed to send Juno into the atmosphere of Jupiter, this will end up in the destruction of the probe as it was not designed to operate in the extreme environment of Jupiter's atmosphere. After the science pass on orbit 37, a deorbit burn will occur which will set the lowest point of the next close pass to be below the clouds tops.

On February 20, 2018 Juno will have completed its mission. The destruction of the spacecraft in Jupiter's atmosphere ensures that its orbit would never place it on a collision course with the Jovian moons Europa, Ganymede, or Callisto. Such an impact would violate NASA's planetary protection requirements.

As of this writing, Juno is currently in its first capture orbit, speeding back towards Jupiter, the science instruments are on and while the first orbit is not technically a science orbit, some readings, and certainly some images will be gained during the pass around Jupiter.

The first actual science orbit doesn't begin until the middle of November. In the months ahead, more science and images will come back from Jupiter. What will we discover and what will we see?

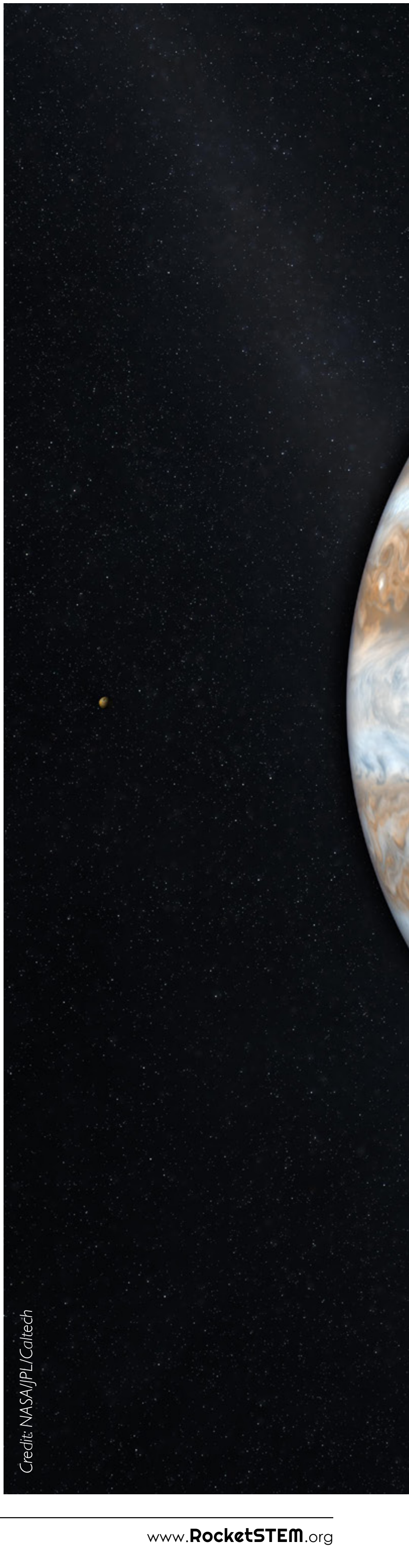
To learn more about Juno and follow its mission, the following websites are very informative :

https://www.missionjuno.swri.edu/

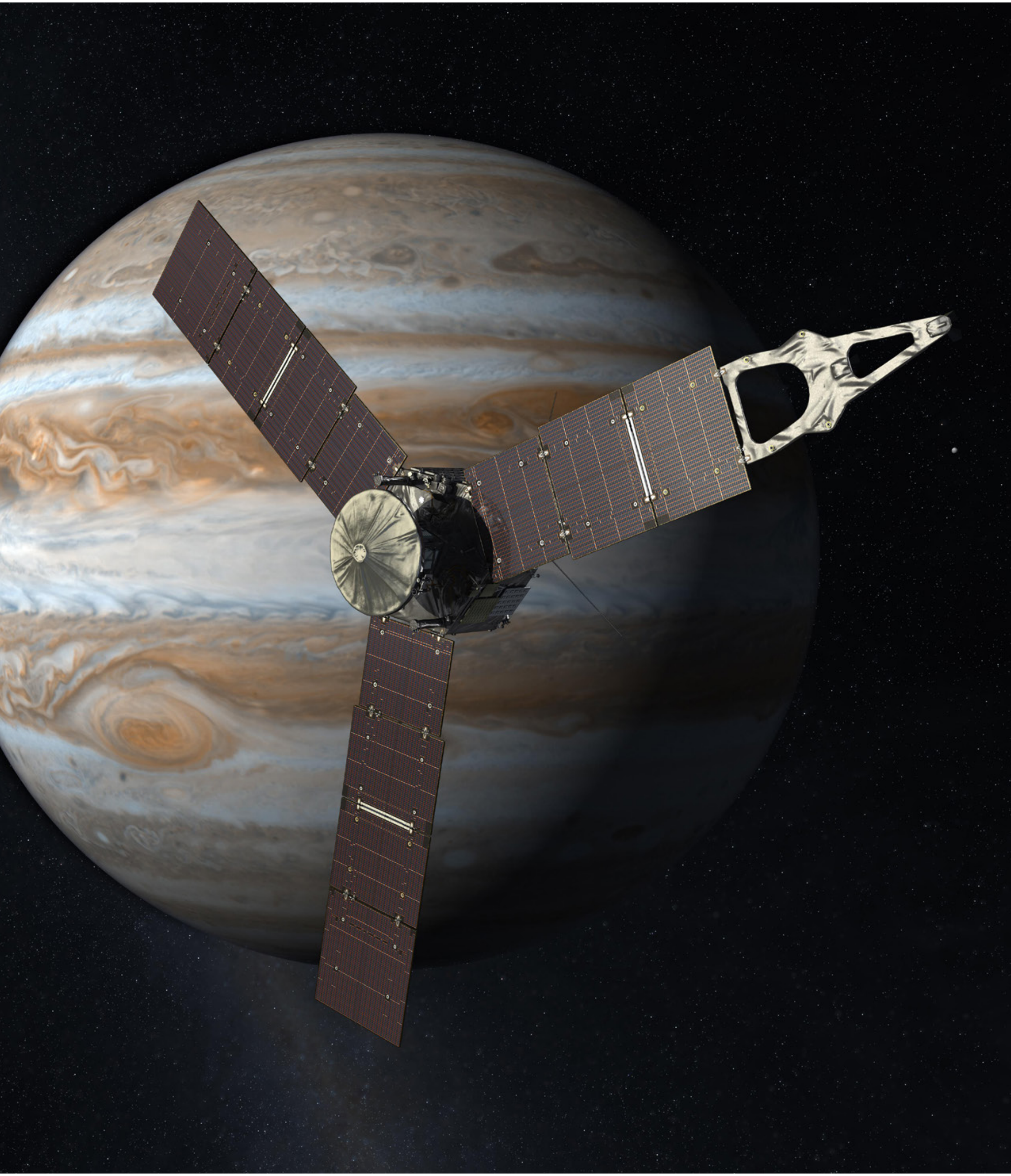
http://www.nasa.gov/mission_pages/juno/main/index.html

To find out where Juno is and "fly along" with the spacecraft, check out NASA's Eyes on the Solar System program. It's an internet-based tool that you download to your PC or Mac and use to see many objects in the solar system, including Juno:

http://eyes.jpl.nasa.gov/juno



Credit: NASA/JPL/Caltech



Myth, mystery and measurement onboard Juno

By Peder Halseide

After traveling for five years, three Lego minfigs from Earth reached the planet Jupiter this summer. Traveling onboard a spacecraft named Juno, these are the first Lego minifigs to visit the largest planet in our solar system. Specially made from aluminum, they are designed be able to withstand the volatile conditions for 37 planned orbits around Jupiter.

The three minifigs represent the god Jupiter, his wife Juno, and the great scientist Galileo, who observed moons orbiting Jupiter over 400 years ago.

What is the significance of these three particular ambassadors, and what secrets do they hold in their little Lego claw hands?

The first Lego minifig is a likeness of the god Jupiter, the Romans' mythical king of the gods. Indeed, Jupiter the planet is massive. Jupiter has two and half times more mass than all the other planets in our solar system. It is so massive that the center of gravity between the Sun and Jupiter (known as the barycenter) lies outside the Sun, causing the Sun to wobble slightly. Jupiter's magnetosphere is so large the Sun could easily fit inside it. Jupiter the planet is an imposing place. It is one of the most extreme environments in our solar system, a cauldron with dangerous radiation, powerful gravity, massive clouds, and awesome ancient storms and aurorae.

Jupiter, the god, was also known as the Norse god Thor from which we get the name Thursday. The Greek name for Jupiter was Zeus, the god of sky and thunder. This designation is fitting since Jupiter, after our own Sun, Moon and Venus, is the brightest object in the sky. Well known to the ancients, Jupiter was described as wandering star (planetai in Greek), which is where we get the word planet. Jupiter, the planet, contains within it the secrets of the formation of our solar system. Jupiter, the Lego minifig onboard Juno, has a long thick god-like beard, and he holds in his right hand bolts of lightning, threatening to annihilate anyone who dares approach.

The second minifig onboard the Juno spacecraft is a likeness of a balding old man, holding in his right hand a model of the planet Jupiter, and in his left hand, a new instrument that had been invented only two years before by Hans Lippershey. The instrument is called a telescope and the old man of course is Galileo Galilei, who at the age of 56 revolutionized religion and science by observing that Jupiter had moons orbiting around it, validating the heliocentric model of the solar system. Galileo's discovery was earth-shattering, in that it replaced the idea of Earth being the center of all things. For the first time, humans had the means to observe objects orbiting a body outside of the Earth or Sun. The telescope in the Galileo minifig's left hand signifies the human quest for knowledge, while his right hand balances the mysterious planet Jupiter. The telescope was not only a technical advancement, but an essential tool that when turned to the heavens "made measurable what is not so."

The third and final Lego minifig on board the Juno spacecraft is the likeness of the goddess Juno herself. She had the power to peer into her wayward husband Jupiter's shenanigans, which he kept from Juno's sight by obscuring himself in clouds. Juno used her power to peer through the clouds, and gained knowledge and insight about Jupiter. Juno, the Lego minifig holds in her right hand a magnifying glass, symbolizing her ability to look closely at what was once obscure.

The Lego Jupiter minifig holds lightning to symbolize the power and mysteries of the planet Jupiter. The Lego Galileo minifig casts his eye upon Jupiter from far away, and from 400 years ago through a telescope. Now, Juno the spacecraft, standing on the success of science and innovation, brings us closer to Jupiter than we could have imagined not that long ago. The minifig Juno's magnifying glass symbolizes the array of advanced and sensitive instruments onboard the Juno spacecraft, which will help us answer some of the important questions about the nature and formation of Jupiter. Juno represents the best of human kind, of looking carefully and closely at something. Quoting Galileo, "Facts which at first seem improbable will, even on scant explanation, drop the cloak which has hidden them and stand forth in naked and simple beauty." This is the cloud that that the Lego Juno promises to unveil with her magnifying glass.

"All truths are easy to understand once they are discovered; the point is to discover them." -Galileo

The Lego figures onboard the Juno spacecraft are a nod to our humanity, using both myth and science as a way to name, explain and understand phenomena. The instruments they hold are a symbol of the methods and tools we use to discover the truth about ourselves. Just as a telescope was an instrument used by Galileo to radically revolutionize our understanding of our place in the universe, so the scientific instruments held by the Juno spacecraft are a modern-day equivalent of expanding our knowledge. Galileo holds in his hand a telescope, to give us a radical new view from far away, and to plant in our minds the idea of deeper knowledge as we search for Truth. Juno holds in her hand the instruments for us to see up close how Jupiter was formed, and by extension, insight on how our own home planet came to be. These Lego ambassadors tell the story of our journey from myth, to insight, and ultimately, to understanding.

RocketSTEM Word Find

Q	T	S	S	N	A	E	L	R	O	W	E	N	V	F	E	P	P	N	H
O	Q	N	W	P	N	O	H	B	A	J	U	N	O	Q	A	V	E	Q	M
R	I	O	O	S	I	R	I	S	R	E	X	K	D	I	M	G	A	D	T
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Galileo Galilei
Atlas V
Hydra
Liquid Water
Atlantis
Centauri
Planet
Rocket
Cape Canaveral
Pluto
California
Charon
Styx

Europa
New Orleans
Callisto
Asteroid
Bennu
Kuiper Belt
Florida
RocketSTEM
Jupiter
Apollo
Proxima b
Habitable
Plasma

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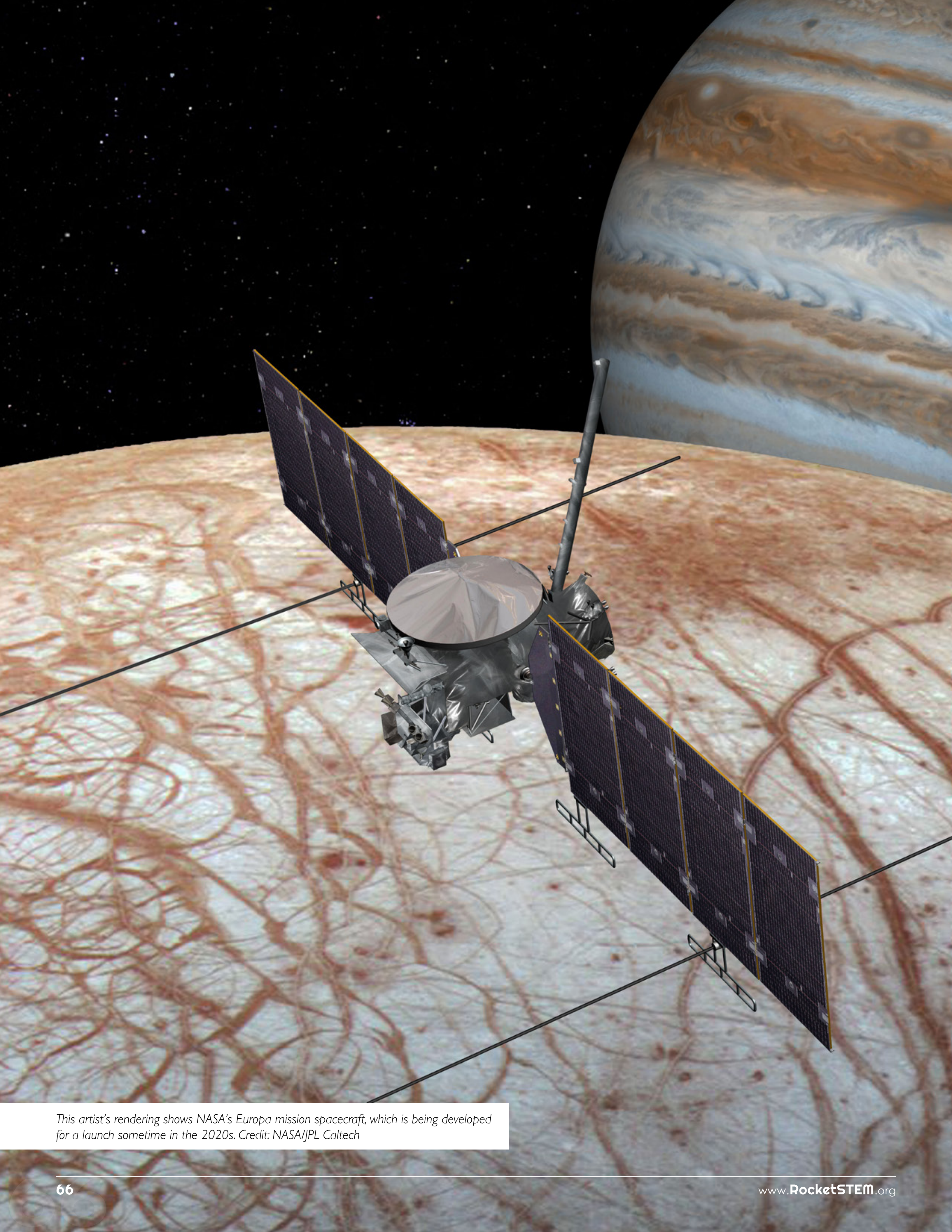
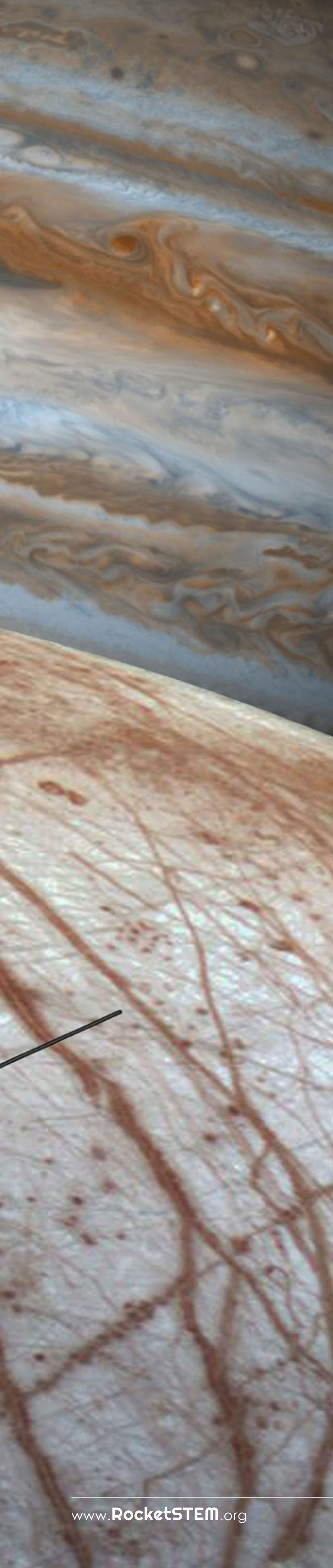
New Horizons



This artist's rendering shows NASA's Europa mission spacecraft, which is being developed for a launch sometime in the 2020s. Credit: NASA/JPL-Caltech



Life on a moon?

Exploring Europa

By Sherry Valare

On a clear night, you can see the planet Jupiter with nothing more than your eyes, as it shines steady and bright against the background of glittering stars. If you take a closer look through a telescope, you can see tiny specks surrounding it. What if I told you that there may be life on one of these specks?

NASA is about to embark on a mission to explore yet another unexplained part of the solar system. This search is spurred by the existence of a massive, ice-covered, water world type moon, which could very possibly be the home of a plethora of extraterrestrial aquatic life. This intriguing moon, filled with so much possibility, belongs to Jupiter and its name is Europa.

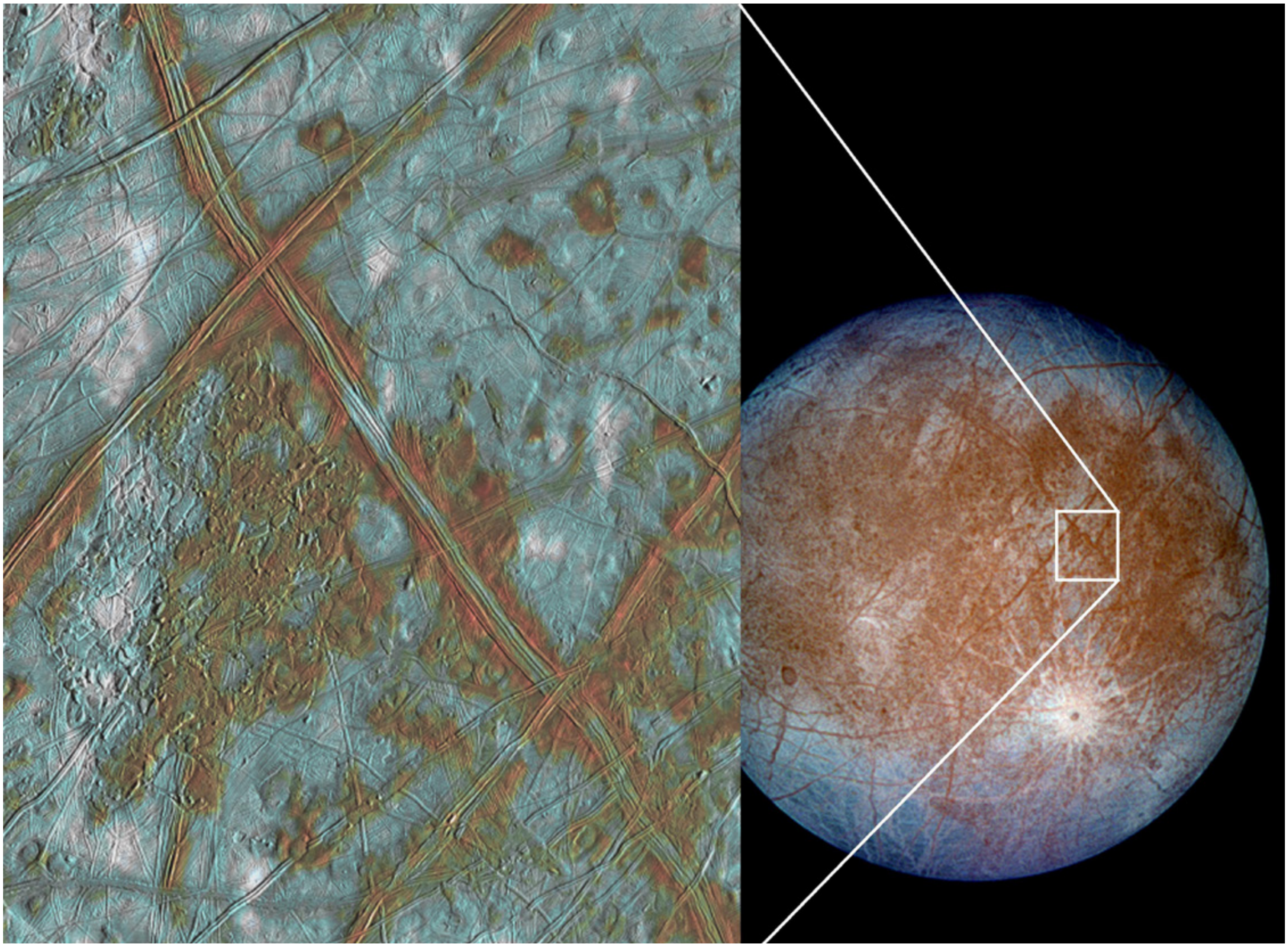
It is finally time to find out exactly what is happening on this moon. NASA announced earlier last year that they are going forth with a mission to this icy world with high potential for housing life. According to Dr. Curt Niebur, program scientist on the Europa mission, there is an urban legend that back in the 1990s at a science conference, a video conference was held with 2001: A Space Odyssey author Arthur C. Clarke himself, who gave NASA his permission to land on Europa, despite his original warning to avoid an attempt.

Europa is one of four large moons discovered by the astronomer Galileo, four hundred years ago. Today, we now know that under its many miles of icy crust, there may exist an environment highly conducive to supporting some form of life. Just like our own Moon, as Europa orbits its planet, it undergoes tidal flexing. This makes it flex and stretch. As this occurs, it warms the interior of Europa with the heat it creates. It is possible that this action may be responsible for volcanic activity occurring – similar to the activity on another one of the Galilean moons – Io.

Since the late 1990s when NASA's Galileo mission gave scientists solid evidence of a sub-surface ocean, it has been speculated that due to the possible recipe of a saltwater ocean, a rocky sea floor, and the energy and chemistry that tidal heating gives, Europa could be harboring life in the form of simple organisms. When I asked Dr. Niebur if he thinks life exists on this moon, he answered, "I don't know. But I think that that's the big question. What I think, is that Europa is the most habitable place in our solar system, beyond Earth."

The idea behind the mission is to complete an assessment of Europa and inspect its potential for harboring life. This mission concept is now going into phase known as formulation – otherwise known as the development phase.

Here is how it will happen. In the 2020s, a spacecraft loaded with instruments and tools to conduct experiments will launch on a 6.5 year expedition heading towards planet Jupiter. Every two weeks, the satellite will travel



Jupiter's moon Europa has a crust made up of blocks, which are thought to have broken apart and 'rafted' into new positions, as shown in the image on the left. These features are the best geologic evidence to date that Europa may have had a subsurface ocean at some time in its past. Credit: NASA/JPL/University of Arizona

around Jupiter, offering it numerous chances to perform up-close flybys past Europa. The team has planned for this to happen 45 times, at distances ranging from 1700 miles (2700 kilometers) to 16 miles (25 kilometers) away from the surface, so that the spacecraft can collect high-resolution images.

The responsibility of project management will fall on NASA's Jet Propulsion Laboratory, where a team has been collaborating with the John Hopkins University Applied Physics Laboratory (APL) to study the mission concept of the spacecraft taking multiple passes of the moon.

Nine instruments have been chosen to hitch a ride on the satellite sent to Europa. Scientists will learn about the composition of the surface when cameras and spectrometers snap high-resolution photos and send them back for analysis. A radar will be utilized to penetrate the icy shell to measure its thickness and determine if lakes, comparable to those that reside underneath Antarctica's ice sheet, exist underneath it. The strength and direction of Europa's magnetic field will be measured by a magnetometer to figure out the depth and salinity of the subsurface ocean.

The mission will also observe the surface with a thermal instrument to look for recently erupted areas of warmer water. As a matter of fact, when I asked Dr. Niebur what part of the mission he is most looking forward to and if there is anything specific he would personally would like to know, he told me, "The idea of water lakes embedded in the ice shell near the surface is really fascinating to me. And I think that this mission will be able to find those if they exist. I also think in the future, when we do land and we do drill, it's going to be the lakes that we target, because they are going to be closest to the surface and easiest to get to."

Other instruments on board will look for confirmation of water and small particles in the atmosphere of the moon. In 2012, the Hubble Space Telescope made a notable discovery of water vapor above the southern polar region of Europa, which could possibly be evidence of the existence of water plumes. If this is proven true, studying their composition could provide clues to the possibly life-sheltering environment's chemical makeup, making it less necessary to drill into the thick crust to find out.

The research instruments were supplied by various institutions including: APL; JPL; Arizona State University, Tempe; University of Texas at Austin; Southwest Research Institute, San Antonio and the University of Colorado, Boulder. The list of instruments selected to make the trip are as follows:

- Plasma Instrument for Magnetic Sounding (*PIMS*)
- Interior Characterization of Europa using MAGnetometry (ICEMAG)
- Mapping Imaging Spectrometer for Europa (MISE)
- Europa Imaging System (EIS)
- Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)
- Europa THermal Emission Imaging System (E-THEMIS)
- MAss SPectrometer for Planetary EXploration/Europa (MASPEX)
- Ultraviolet Spectrograph/Europa (UVS)
- SUrface Dust Mass Analyzer (SUDA)

Information gained from this mission (which has yet to be officially named, but informally is called "Clipper" by those working on it) could eventually lead to the creation of further pursuits.

When asked if a lander is included in the plans, Dr. Niebur stated, "We are studying a lander. Our analysis shows that it makes the most sense to launch it about 2 years after Clipper is launched. We currently have a Science Definition Team working on finalizing the scientific goals of the lander, but its primary objective will be to search for evidence of life. It will land, use a drill of some kind to collect ice samples, and then deliver the samples to science instruments for analysis." Science instruments for the lander have not yet been chosen.

What exactly will NASA find when it starts to examine all of the mystery surrounding this world? That is yet to be answered, but if speculation proves to be truth, discoveries made about Europa could force us to come to terms with the existence of life outside of Earth.

What do you think that life look like? Will it be plant or animal? How would Jupiter appear in the sky when looking up from Europa's surface? "Europa is tidally locked, meaning the same side of Europa always faces Jupiter (like Earth's moon). If we land on the side of Europa facing Jupiter, then I promise you we will have pictures of Jupiter hanging above Europa's landscape. And Jupiter would be about 20 x larger than the Earth's moon looks from the surface of Earth," says Dr. Niebur.

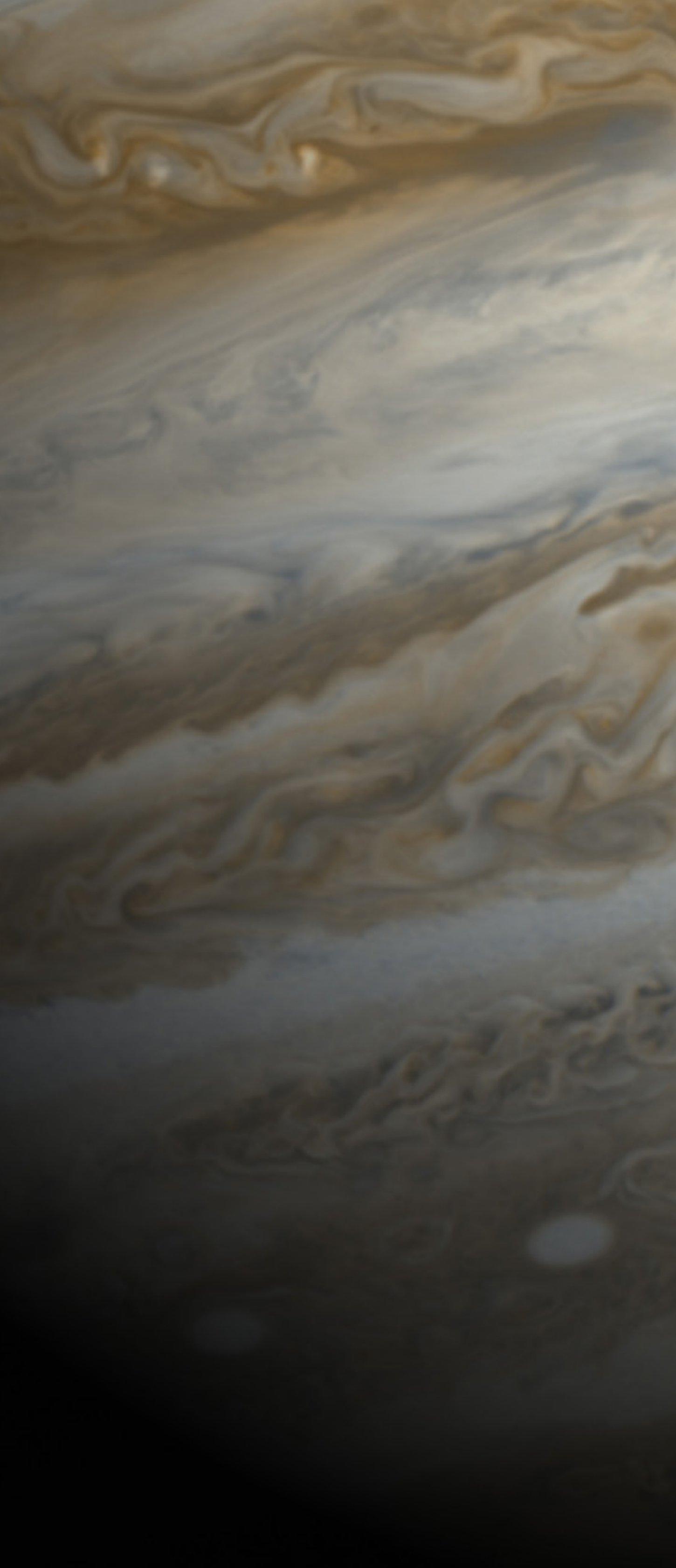
This little, intriguing moon could hold one of the most poignant discoveries of our lifetime. With such irresistible potential, even Arthur C. Clarke had to make an exception to his famous ban on attempting a landing there.

Credit: Jet Propulsion Laboratory

The Jovian System

By Mike Barrett

The Jovian system encompasses Jupiter, its rings and moons. Jupiter was reputedly discovered by the Babylonians some 9,000 years ago. Its moons were discovered by Galileo, in 1610, observed through a refracting telescope.



The Planet Jupiter

- Jupiter is the fifth planet in our Solar System counting out from the Sun. It is 5.2 astronomical Units away from the Sun, or 5.2 times further away from the Sun than the Earth.

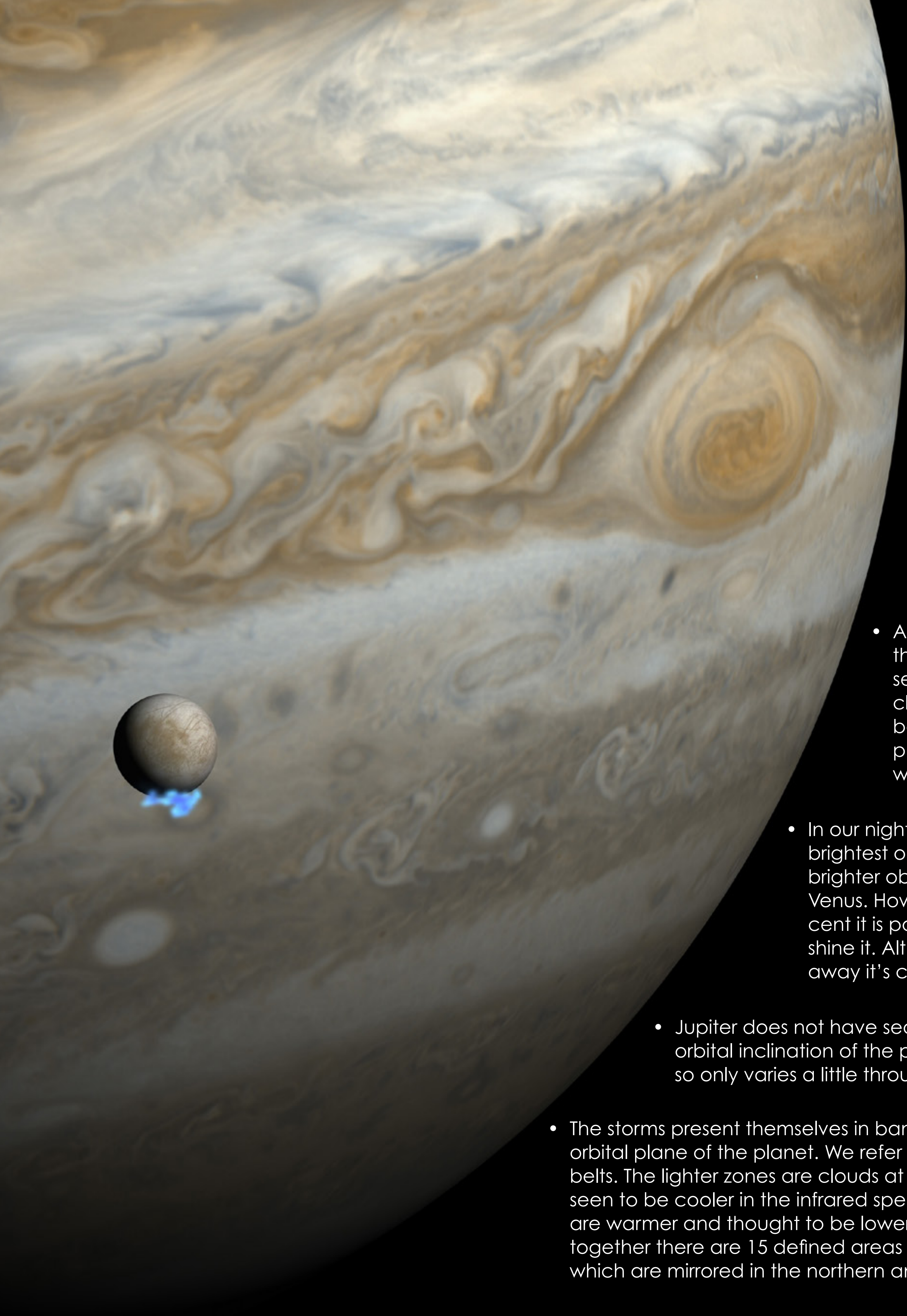
- A Jovian year is 11.9 Earth years, but the Jovian day is just 9 hours 55 minutes.

- Jupiter has an equatorial radius of about 44,000 miles compared to the Earth's of just under 4,000 miles, making it 11 times larger than the Earth. It is the largest of the Gas Giants which makes it the biggest planet in the Solar System. Jupiter is so big that it contains more matter than all of the other planets combined.

- Jupiter is a Gas Giant, with it's atmosphere being mainly composed of hydrogen and helium. In this respect it is very similar to the Sun with a mass proportion of around four hydrogen to one helium.

- The apparent surface of the planet if formed of gaseous clouds. These clouds are active in a very violent storm system. The storms last very long periods of time as there is no land mass to disperse them.

- Little is known about the internal composition of the planet, but it is speculated that it has a small, very dense rock and ice core that is encompassed by dense metallic hydrogen. As it is not possible to see through the clouds the presence of a surface cannot be determined. It is possible that there is no surface and that an object sinking through the atmosphere would just become more and more compressed the lower it went.



Credit: NASA/ESA/M/Kornmesser

- As Jupiter is always outside the Earth it is always observed as a disk. Planets closer to the Sun can often be seen as crescents, but planets further from the Sun will always be seen as disks.

- In our night skies Jupiter is the third brightest object to be seen. The brighter objects are the Moon and Venus. However when Venus is in crescent it is possible that Jupiter will outshine it. Although Jupiter is a long way away it's clouds are very reflective.

- Jupiter does not have seasons like the Earth as the orbital inclination of the pole is about three degrees so only varies a little throughout the 11.9 year orbit.

- The storms present themselves in bands whirling around the orbital plane of the planet. We refer to these as zones and belts. The lighter zones are clouds at a higher altitude and are seen to be cooler in the infrared spectrum. The darker belts are warmer and thought to be lower in the atmosphere. Altogether there are 15 defined areas in Jupiter's atmosphere which are mirrored in the northern and southern hemispheres.

- The most famous feature of the Jovian atmosphere is the storm known as the Great Red Spot. It was documented in 1899 in the Monthly Notices of the Royal Astronomical Society, but there were even earlier scientific observations from H Schwabe in September 1831, and it may well have been observed before that. The Great Red Spot is easy to view in a modern small telescope on a night with good visibility when Jupiter is high in the sky.

The Moons of Jupiter

- Most people think that Jupiter has four moons. They are wrong! There are in fact 67 recognised moons orbiting in the Jovian system. However there are four that are large and easily visible from Earth using a small telescope.

- Galileo is credited with discovering the first four main moons hence them being called the Galilean Moons. This initial discovery was made in 1610. The latest Jovian moon to have been discovered was not long ago in 2011.

- The moons of Jupiter are split into two main categories: those with regular orbits and those with irregular orbits. The moons with regular orbits travel round Jupiter in an almost circular orbit aligned with the planet's equatorial plane. The irregular moons have elliptical orbits, high inclinations and are much further away from Jupiter.

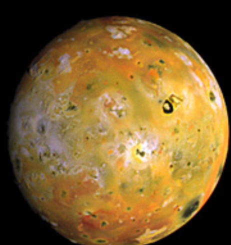
- The moons vary dramatically in size from 1km in diameter to over 5,200km. Ganymede is the largest and there are 48 moons with a diameter of 5km or less.

The Galilean Moons

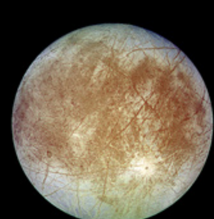
- Of the four moons Galileo discovered, Ganymede is the largest, followed by Callisto, Io and Europa. Ganymede is in fact the ninth largest body in the solar system and is bigger than Pluto and Mercury.

- The Galilean Moons are the fifth through eighth closest of the known moons orbiting Jupiter. Io is the closest with Europa, Ganymede, and Callisto outside it.

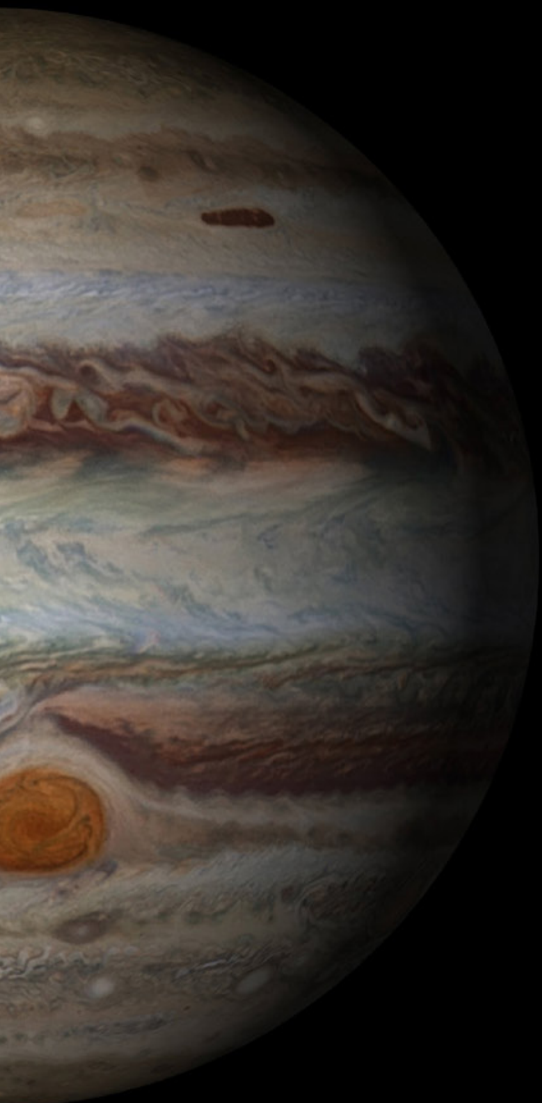
- Io, the closest of the Galilean moons, is the most dense of the moons and is highly volcanic. Its surface is therefore very young. Io's core is thought to be made up of iron and iron sulphide, there is then a mantle of igneous rocks, the viscous upper layer of the mantle then the outer crust of the moon. This composition is similar to the inner planets. Formed at about the same time as Jupiter it has an orbital radius of around 260,000 miles.



- Europa, the smallest of the Galilean moons, orbits outside Io. Europa is thought to be the ocean planet, with a vast watery ocean lying under a crust of ice. It is speculated that the gravitational effects of Jupiter create tides that in turn warm the water. The composition of Europa presents the highest probability for the discovery of life as we know it in the Solar System. The Hubble Space Telescope has recorded huge spouts of water vapour jetting from the surface. The moon orbits at just over 415,000 miles from Jupiter.

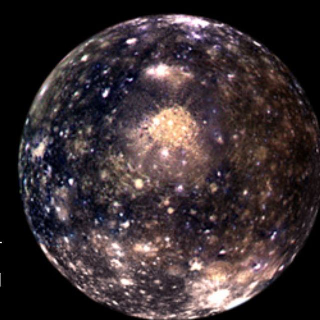


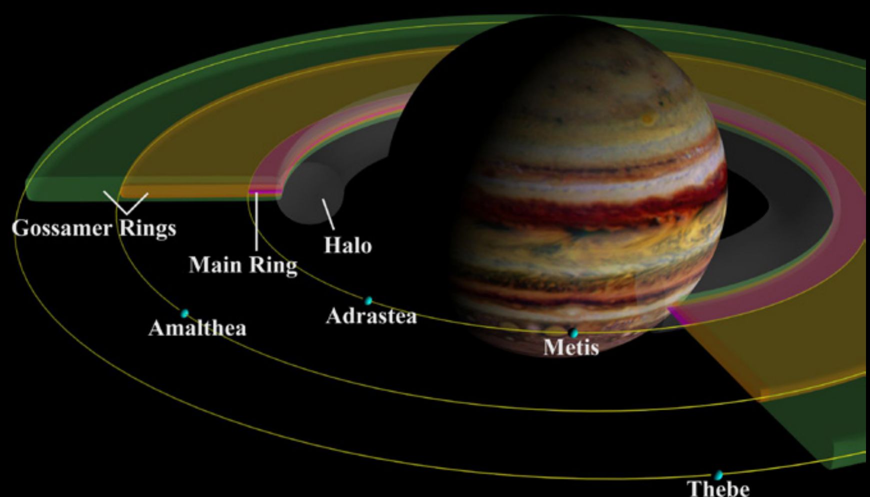
Credits: NASA/JPL



- Ganymede is the next moon out orbiting at over 660,000 miles. It is the largest known moon in the Solar System, almost double the size of Earth's Moon. It is composed of silicate rocks (similar to Earth) and water ice. Ganymede has a small ferrous core that generates a magnetic field about 1% the strength of the Earth's. The surface of this moon is old and pockmarked with craters from impacts. In 2015 the Hubble Space Telescope found evidence that there may be a huge underground ocean containing more water than Earth.

- Callisto is the furthest out of the Galilean moons orbiting at about 1.1 million miles. The surface of Callisto is the oldest in the Solar System, it also has the most cratered body in the solar system. The implication of this is that there is no volcanic or teutonic activity on the moon which renews the surface. The moon is thought to have a small rocky core and has been proven to contain water ice, carbon dioxide, silicates and organic compounds. It is believed that underneath a 124 mile thick crust lies a salt water ocean some six miles deep.





The Rings of Jupiter

- Possibly the least known fact about Jupiter is that it has rings. In fact there are three rings which orbit inside the Galilean moons. These are known as the halo, the main ring, and two gossamer rings from inner to outside. It is believed that the rings are made of small dust particles, not ice. The space probe Galileo confirmed that the main ring was formed from deposits from the inner moons Adrastea and Metis, the two closest moons of Jupiter. The gossamer rings from the small moons Amalthea and Thebe. The rings were first discovered in 1979 by the Voyager 1 spacecraft. They are so faint that they can only be seen looking through them towards the Sun.

Once more with feeling

L.A. welcomes another Space Shuttle artifact

By Mary Kanian and Julian Leek

Hollywood…the very name creates visions of stars…okay…mostly 'human stars.' But every bit as popular throughout film history, 'reaching for the stars' has been a popular theme from comic books to radio, TV and film. Buck Rogers, Superman and Flash Gordon stirred youthful imaginations with visions of interplanetary travel and grasping for the stars ever since the Wright Brothers' flying machine finally got us off the ground early in the last century.

The people of Los Angeles thronged the streets in 2012 to welcome the Space Shuttle Endeavour home to her birthplace, and final showplace of honor at the California Science Center, located in the heart of Los Angeles across the street from one of the country's premier learning institutions, the University of Southern California, known as USC. Here she would be garaged until funding could be raised to build a structure suitable to display her in a meaningful way. That plan began to gel soon after her arrival, when fundraising began.

The idea to display Endeavour in her stacked arrangement, as they call it when the fuel tank and solid rockets are assembled and attached to the orbiter, came about when NASA was looking to scrap or salvage some of the many left-over Shuttle components laying around unused. A rather sizeable one of these was one of only two existing external fuel tanks left over from the concluded Shuttle program.

One was a mock-up fuel tank, never designed to be flight-worthy. NASA uses these mock-ups for study and training purposes, especially useful should something go wrong, which indeed it did when the Columbia broke during re-entry over Texas, effectively dooming the Shuttle program.

The second fuel tank was flight-worthy and ready for use in the next mission to be flown by Columbia.This same External Tank was used to test the foam insulation that covers it to see if the bits of it that sometimes broke loose during launch were in any way capable of damaging the leading edge of the orbiter wing. Scientists

Crowds lined the 16-mile route as the last flight-ready Space Shuttle External Tank was paraded through the streets of Los Angeles earlier this year. Credit: Julian Leek/JNN discovered to their surprise that this lightweight insulating material could indeed puncture a hole in the leading edge of the wing. The tragic loss of the Columbia also led to the realization that a way to inspect and repair damage to the surface of the vehicle, post-launch, would have to be developed.

The huge External Tank, to which the orbiter is affixed, is the last part to be jettisoned after launch and largely burns up over the ocean during re-entry. With the demise of Columbia, a large piece of history had been orphaned and its very existence was hanging in the balance between making history or becoming history. Luckily, someone realized what a treasure and opportunity they had in the one remaining flight-worthy External Tank.

About two years ago NASA agreed to gift External Tank #94, or ET-94 as it is commonly called, to the California Science Center. All the center had to do was arrange transportation. A chain of events and major planning immediately got underway. The tank was huge in size and certainly not flyable by plane as the orbiters had been. The move would require careful and special handling all the way. Only a handful of companies were qualified to perform such a move and handle it pretty much "door to door."

Emmert International, a huge engineering and logistics giant with assets located all over the world, had the know-how and experience to fearlessly move almost anything from here to there. Masters of meticulous planning, they arranged everything from pickup of the tank from its home at NASA's Michoud Assembly Facility near New Orleans, to transfer onto a specially fitted barge and subsequent passage through the Panama Canal (a first for an External Tank). Sounds simple…yet the dimensions of the bulky tank and the distance involved were daunting.

At 154 feet in length, the ET stands at the equivalent of a 15-story building and actually dwarfs the orbiter itself in launch position, where the massive ET looks like a canvas upon which the shuttle has been painted. The orbiter, however, is much heavier than the ET…which was shipped empty, of course, yet still weighed a 65,000 pounds.

The tank's diameter is a slim 27.5 feet…much narrower than the span required by Endeavour to traverse the streets of Los Angeles, significantly reducing the impact on the trees and streets of the metropolitan area…which was minimal by comparison to the Endeavour move. There was, however, a blizzard of permits that had to be sought from the various cities through which the entourage had to pass thorugh during the 16 mile move from the coastline to the museum. There were a number of municipalities and utilities that had to be consulted and carefully coordinated with in order to move signals, signage and electrical wires during the move. Making the 90-degree turns along the route was the major challenge this time. While the wheels on the trailer could be turned 90 degrees, the rig itself could not back up. Each turn had to be precisely engineered and executed in forward motion only.

A lot could have gone wrong – but didn't – during the 41 day voyage of 4,400 nautical miles journey through the multiple locks and the traffic of the busy Panama Canal. There was a moment of drama that occurred when ET-94 and her tow-barge encountered

ET-94 passed from the Atlantic Ocean through the Panama Canal Gatun locks in Panama on April 25. The tank spent the night moored in Gatun Lake before traveling through a final set of locks into the Pacific Ocean the following day. Credit: Jason Davis / The Planetary Society (CC BY-NC-SA 2.0)

a charter fishing boat sinking off the coast of Mexico with four men in urgent need of rescue. It required great skill on the part of the skipper to pause and rescue the fishermen without putting his cargo at risk. The rescued fishermen were transferred to safety in Sand Diego, where even this unusual cargo was required to go through Customs inspection.

It was amazing that it all worked out so well that she arrived right on schedule on May 18 at Marina del Rey where a special Mardi Gras-style Gala fundraiser was planned for the evening of May 20 in a large and elegant tent pitched right next to the tank itself, which had been offloaded from the tow-barge. ET-94 and host of well-heeled guests were royally welcomed by museum officials and a smiling Mrs. Lynda Oschin who, along with her late husband, Samuel Oschin are the main benefactors of the California Science Center.

With the addition of ET-94, the California Science Center's Samuel Oschin Air and Space Center will be the only place in the world that people will be able to go to see a complete Space Shuttle stack – orbiter, external tank, and solid rocket boosters – with all real flight hardware in launch configuration.

After an evening of celebration, ET-94 began the final leg of its journey at midnight---the 16-mile trek eastward to the museum, which was projected to require 18-20 hours to complete. This move was shorter than Endeavour's move, which had originated from LAX and took three days to complete. The Shuttle move was conducted among a celebration of huge crowds along the lengthy route with stops in various locations for speeches, a stage show and making a number of tight turns and maneuvers along the route. The jubilant crowds back then sometimes had to bide their time for hours due to unforeseen delays in the tight spots where wheel sets had to be physically moved to get around obstacles.

ET-94 may not have had quite the sex appeal of a Space Shuttle, but it was definitely a sight to behold. Rolling a 15-story cylinder on its side through the city streets of Los Angeles is no mean feat.

The crowds turned out for this move too. They were awed by the ET's size and presence. Many people came because they had been there for the Endeavour's arrival. Others flocked to the route because they had missed seeing the Shuttle arrival and didn't want to miss another once-in-a-lifetime experience.

As with the Space Shuttle, young people kept asking if this was the real Space Shuttle, or a replica? They found it hard to believe that these very objects were the real deal. That Endeavour had indeed gone to space and back a number of times…and that ET-94 had been meant to go to space had its orbiter not met with tragedy. And they could scarcely believe that the scars on the rust-colored body of the ET were caused by taking pieces of its foam covering for testing to determine what had gone wrong with the orbiter and how it could have possibly been damaged by a piece of lightweight foam.

Oh, there is still much to be learned from this spectacular pioneering form of space travel…the most complicated piece of machinery ever built by mankind…and we did it here, in the USA, over and over again. No doubt, Buck Rogers and Flash Gordon would feel very much at home at the Space Shuttle exhibit when it opens.

While not having to navigate normal L.A. traffic, the journey through the city still took 18 hours to complete. Credit: Julian Leek/JNN

Scenes from ET-94's parade to the California Science Center. The External Tank will eventually be mated with Space Shuttle Endeavour and displayed in a vertical, lauch-ready configuration. Credit: Julian Leek / JNN


Science Center
African American
MUSEUM
Sports Arena
WELCOME
HOME
ET
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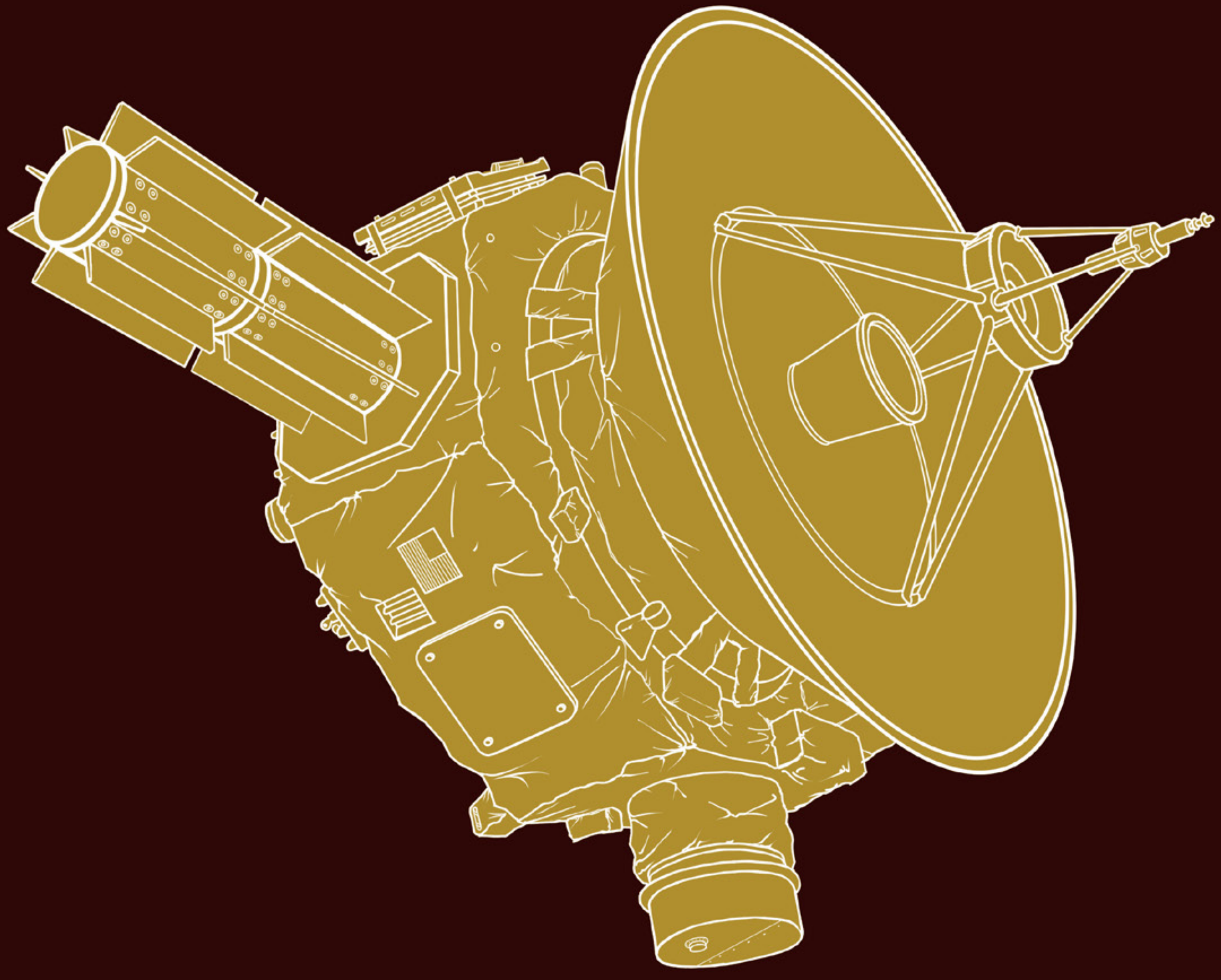


Artist's illustration of the New Horizons spacecraft. Credit: Sebastian Kings

NEW HORIZONS

Glittering prizes within Pluto data

By Chris Starr FRAS FBIS

It is exactly one year since New Horizons hurtled through the Pluto system at 49,600 km/h, after a journey of nearly nine and a half years, its array of scientific instruments gathering precious data on this hitherto mysterious world and its family of moons. We shared in the thrill of the flyby and then watched in awe as a new world was finally revealed in all its beauty and complex detail. The final approach of the probe, its flyby, the first images and data were featured in RocketSTEM last summer.

Since its historic encounter, the 400kg spacecraft, the first to explore the dwarf planet, has been slowly transmitting back to Earth the wealth of data collected last summer and stored in its onboard computers. As of July 2016 about three-quarters of the 50-plus gigabits of data collected have been downloaded. This has enabled the science team to build up a comprehensive portrait of the dwarf planet, its five moons and their environment in space.

What was little more than a point of light for much of the 85 years since its discovery by Clyde Tombaugh in 1930, is now revealed in detail as a real world. The results so far are spectacular and surprising. In the words of Dr. Leslie Young, New Horizons' Deputy Project Scientist, 'Pluto did not disappoint. It was the star and we were the paparazzi!'

This article provides an overview, one year on, of the discoveries made so far from its brief encounter, as well as some of Dr. Young's reflections on the mission and her role in planning the encounter.

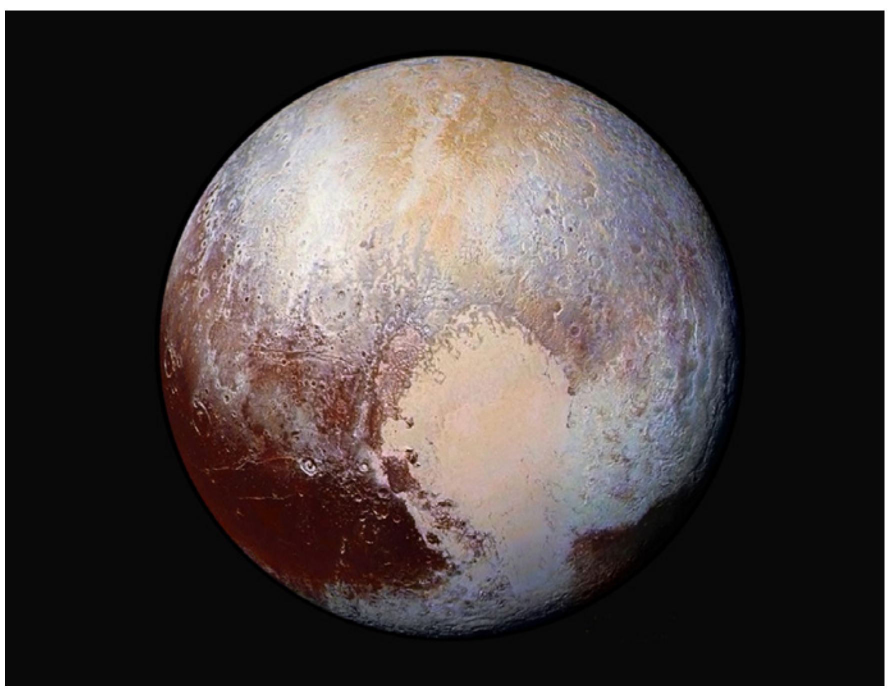


Figure 1: Iconic image – the enhanced-colour portrait of Pluto taken by New Horizons' Long Range Reconnaissance Imager (LORRI) from a distance of 450,000 km (280,000 miles). Centred on the 'heart' of Tombaugh Regio, it shows features as small as 2.2 km (1.4 miles). Four images were combined with colour data from the Ralph instrument to create this view. Credit: NASA/JHUAPL/SwRI

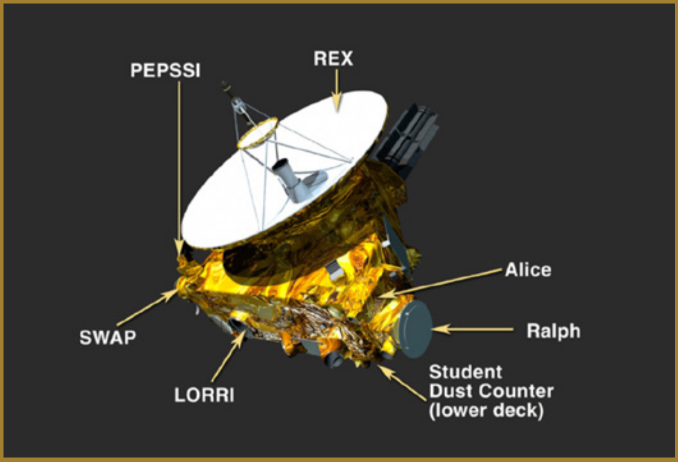
Eyes wide open

At a mean distance from the Sun of 5.9 billion kilometres, some 39.5 times further away than the Earth, where mean temperatures are only 33K (minus 240°C), one might expect these worlds to be inert and frozen, cratered relics bearing mainly the scars of the violent early days of solar system formation. However, previous missions, from Voyager to Cassini, have taught us that the outer solar system is far more exotic and active than we would ever have imagined. In particular, Voyager 2's 1989 flyby of Triton, Neptune's largest satellite, with its interesting chemistry, atmosphere and nitrogen 'geysers', hinted at exciting things to come from New Horizons. This was especially so as Triton was thought possibly to be a near 'twin' of Pluto.

Accordingly, New Horizons was equipped with a suite of sophisticated scientific instruments, so as to have its eyes (and other senses) as wide open as possible for the encounter. Previous missions helped inform the choice and design of data-collecting instruments. For instance, as Dr. Young points out, 'One of the things we learned from flying Voyager at Triton was that, boy, if you want to learn what things are made of you really need the infrared!' So, as well as a telescopic, high resolution camera (LORRI), the spacecraft's 'Ralph' instrument was both a visible and infra-red wavelength imager and spectrometer, while the 'Alice' detector operated in the ultraviolet. At such great distances from the Sun, the instruments were designed to function in the cold conditions and low light levels at Pluto and in the Kuiper Belt beyond.

Asking the right questions – New Horizons' science payload

The New Horizons science payload consists of seven instruments – three optical instruments, two plasma instruments, a dust sensor and a radio science receiver and radiometer. It was designed to investigate the global geology, surface composition and temperature of Pluto and its moons, as well as the dwarf planet's atmospheric characteristics – pressure, temperature, structure, escape rate -, and interactions with the solar wind and space environment.



Credit: NASA/JHUAPL/SwRI

Needing to operate so far from the Sun, the whole payload is powered by a radioisotope thermoelectric generator (RTG), running on a total of less than 28 watts. In order to include a maximum of science, but with as little payload weight as possible, 'it represents' to quote the New Horizons team, 'a degree of miniaturization unprecedented in planetary exploration.'

- Long Range Reconnaissance Imager (LORRI) – telescopic camera to obtain high resolution geological data
- Ralph - a visible and infrared imager/spectrometer for colour, compositional and thermal mapping.
- Alice – an ultra-violet imager/spectrometer to analyse the structure and composition of Pluto's atmosphere, as well as searching for atmospheres around Charon and other KBOs.
- Radio Science Experiment (REX) – radiometer to measure composition and temperature of Pluto's atmosphere
- Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI) – energetic particle spectrometer to measure the composition and density of ions escaping from Pluto's atmosphere
- Solar Wind Around Pluto (SWAP) – solar wind and plasma spectrometer to measure Pluto's interaction with the solar wind and the escape-rate of its atmosphere
- Venetia Burney Student Dust Counter (SDC) – a student experiment to measure space dust impacts during New Horizons voyage. Named after the person who, as a child, suggested the name Pluto after its discovery by Clyde Tombaugh in 1930.

Pluto encounter planning

Dr. Young, who is based at the Southwest Research Institute in Boulder, Colorado, describes some key considerations when planning for New Horizons' Pluto encounter and beyond. Describing herself as a 'Pluto person, rather than a spacecraft person' and 'pretty well-rounded when it comes to all aspects of Pluto science', she was also heavily involved in planning the mission as the Pluto Encounter Planning Team Leader. Invited by Principal Investigator Dr. Alan Stern at the mission proposal stage to plot the quality of the data needed, which required her to plan for how the data was to be collected and how well the different instruments might work, she says she 'was in a good position to be his right hand.' She says that her early work on stellar occultation on Professor James Elliot's team at MIT, a field involving meticulous advance planning, and which led to her passion for Pluto, also stood her in good stead. 'It was the discovery that Pluto had an atmosphere while I was working with Jim Elliot in 1988 that changed my life!'

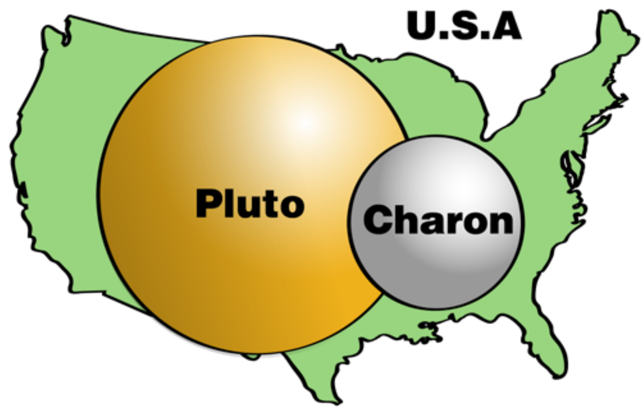


Figure 2: Size of Pluto and Charon compared with America. Credit: NASA

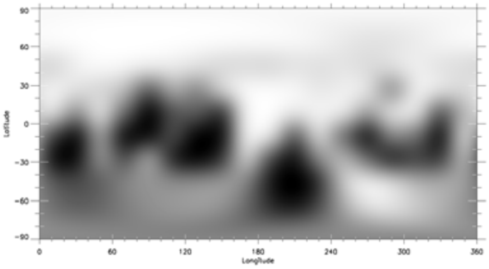
Obviously, Pluto's atmosphere was a key target for New Horizons, as was its interaction with the solar wind and the complex relationship with Pluto's surface, especially regarding the behaviour of volatiles like nitrogen and methane. And then, of course, there was Pluto's large moon, Charon, discovered by United States Naval Observatory astronomer James Christy in 1978. At just over half Pluto's size and about one-eighth its mass (see Fig. 3 for statistics on Pluto and its moons), Charon is large enough to be considered as part of a binary system with Pluto, especially as the two orbit a barycentre (common centre of gravity) outside Pluto itself. Figure 2 shows the sizes of Pluto in Charon compared to that of the USA. Charon's contrasting brightness with that of Pluto and Earth-based observations of its surface chemistry had indicated that it could be an equally intriguing world.

	Diameter (km)	Mean distance from the system's centre± of mass (km)	Orbital period (days)	Mass (10^{19}kg) (Earth = 5.97x10^{24}kg)
Pluto	2,374	2,035	6.38723	1,305 (0.002 Earth's)
Charon (P1)	1,212	17,536	6.38723	158.7
Styx (P5)	16x9x8	42,410	20.16	?
Nix (P2)	50x35x33	48,690	24.85	0.005 ± 0.004
Kerberos (P4)	19x10x9	57,750	32.17	?
Hydra (P3)	65x45x25	64,720	38.20	0.005 ± 0.004

Figure 3: Pluto and its family of moons – Selected statistics. Credit: NASA

Earth-based observations of Pluto's mysterious, mottled surface, barely resolved by the Hubble Space Telescope, also informed the choice of hemisphere for the encounter. Figure 4 shows (a) the best low-resolution mapping of Pluto from Earth compared to (b) the global map of Pluto based on imaging by the New Horizons spacecraft.

Says Leslie Young, 'We knew from early low resolution mapping from the Earth, before we even considered the mission, that Pluto is one of the most contrasty bodies in the solar system. We knew that where you have rapid transitions from very dark to very bright, there's going to be something interesting going on. That's what determined our choice of which side to image at closest approach. I think the findings show that we made the right choice!'



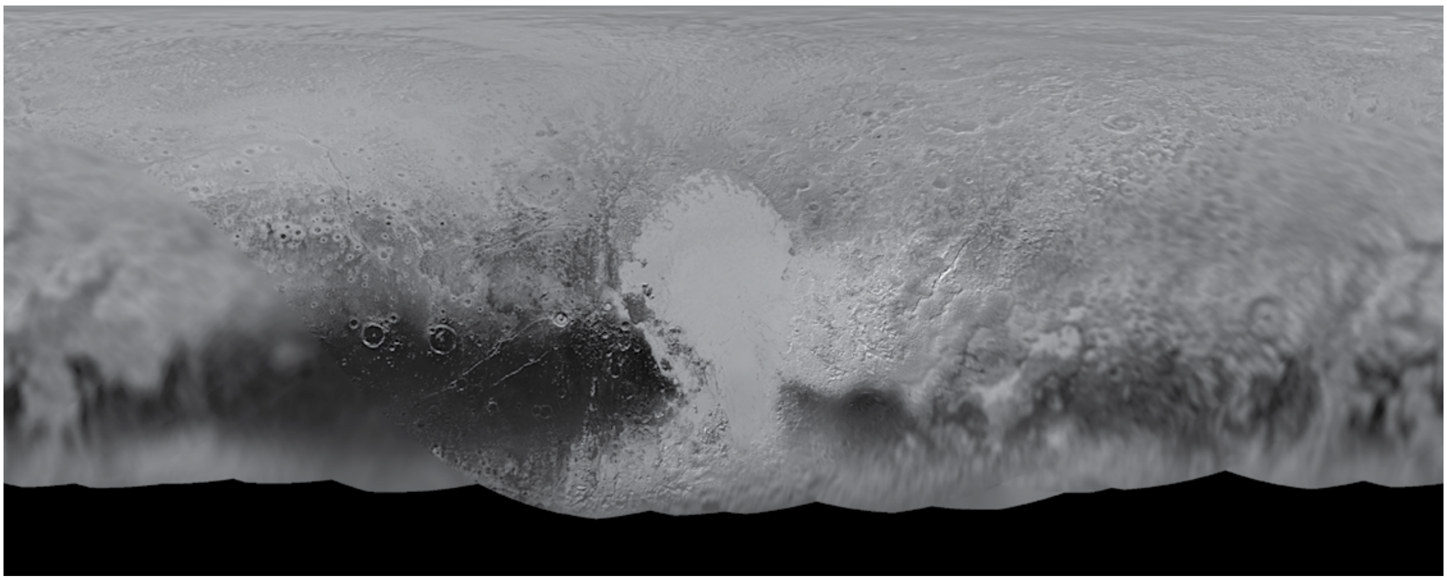


Figure 4 (a): An example of the best pre-flyby maps of Pluto, made from images from the Hubble Space Telescope in 2002 and 2003, showing contrasts in albedo. The target hemisphere was that centred on the equator and a longitude of 180°, the location of the bright feature named Sputnik Planum after encounter. Credit: NASA/JHUAPL/SwRI/Marc Buie

Fig 4 (b): Panchromatic composite global map of Pluto created from images taken at varying distances, and hence, at different resolutions. Sputnik Planum is clearly visible. The dark features along the equatorial region are also clearly resolved. Note that much of the southern hemisphere, currently tilted away from the Sun, is not shown in this map. Credit: NASA/JHUAPL/SwRI

Early surprises – working round Pluto's new moons

New Horizons had a chance to try out its science instruments during its flyby of Jupiter in early 2007, studying the giant planet's atmosphere, magnetosphere, moons and ring system. Even during the long cruise phase of the mission beyond Jupiter, when the spacecraft spent much time in hibernation mode, there was much to keep the New Horizons team occupied. In particular, Leslie Young describes what happened when new moons were discovered orbiting Pluto after the mission had launched in January 2006 (see Fig. 5).

'We got a surprise when we discovered Kerberos and Styx! We'd discovered Nix and Hydra in 2005, which was exciting, two extra targets and we were able to configure in our arrival time and our observing sequence to do a good job on them. When we discovered Kerberos (June 2011) and Styx (June 2012), we thought 'Oh my God! How much else is out there?' We weren't so much worried about hitting a moon, the odds are really small, but if you get a moon and meteorites hitting it, they'll knock off dust which will hang around in the system because the moons don't have enough gravity to hold onto it. If you hit something the size of a chick-pea, it could be a bad day for New Horizons! So we had that period of about two years of unscheduled and nerve-wracking work, taking simulations with pieces of the spacecraft to fancy gun-ranges and coming up with entire new trajectories – what we called SHBOTs (Safe Haven by Other Trajectories) - and whole new observing plans to make things less vulnerable.

In case of problems, there were two tricks we could use. One was to skim the top of Pluto's atmosphere where it would cut down on some of the dust through atmospheric drag. And the other was to turn New Horizons itself so that the antenna would shield the rest of the spacecraft.

Another thing we did was to practise running the whole encounter through, having somebody invent data from the satellite. We ran the simulation three times, as it would be by the clock, with data coming down, people detecting moons, calculating orbits, calculating how much stuff there would be and how risky that might be. We simulated making recommendations, with NASA officials there to run through the procedure. In the end, all of that was very useful because it turned out that to get anything risky we had to have a thousand satellites hiding in between Pluto and Charon to even make us consider trajectory changes. And it helped us make sure we got the best data in the end. Everybody was very happy with the final decision. Everybody was holding their breath a bit on encounter day, but it all went perfectly.'

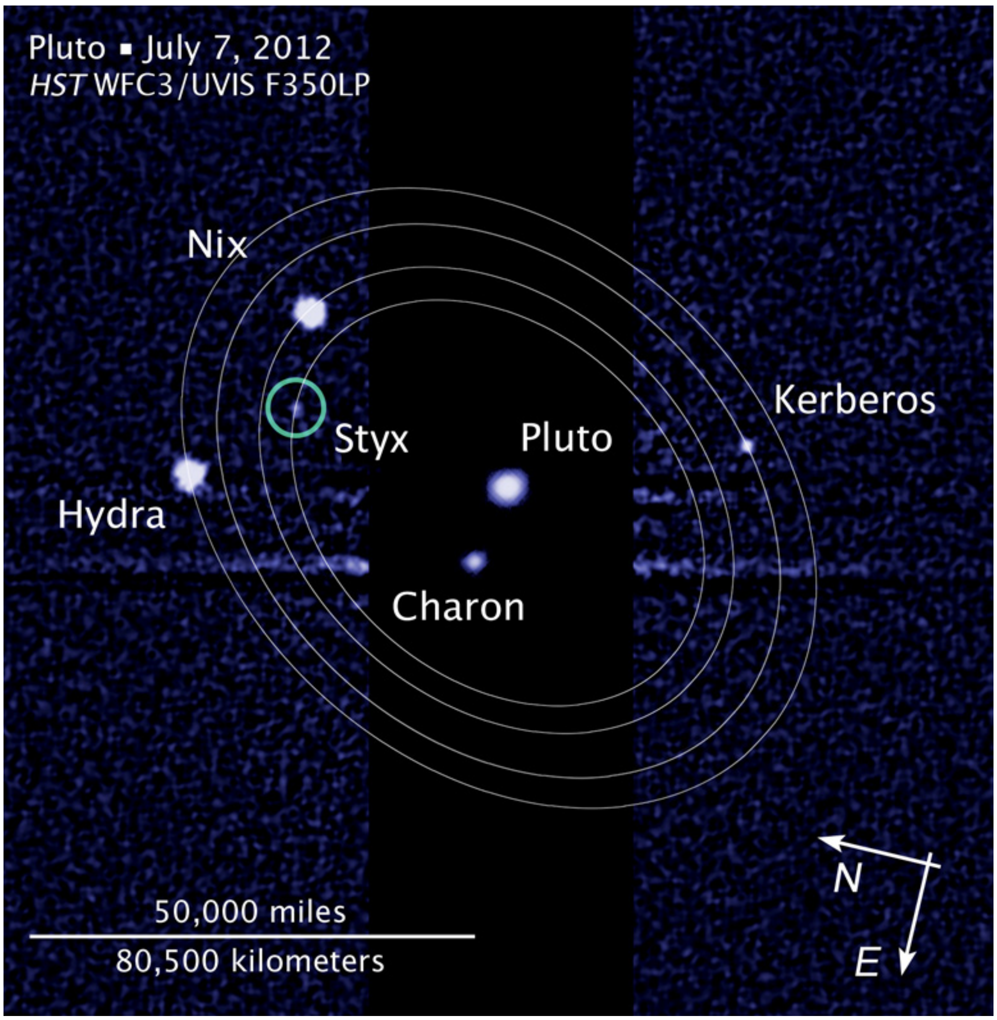


Figure 5: Discovery image of Pluto's tiny moon Styx in 2012, overlaid with orbits of the satellite system, which gave cause for concern to the Pluto Encounter Planning (PEP) Team. Credit: NASA/ESA/L. Frattare (STScI)

Complex and dynamic world

So what have the New Horizons' team learned so far from the encounter? It is beyond the scope of this article to describe all the discoveries made by the spacecraft, so we focus here on some of the most significant ones. (A list of recommended further reading is suggested at the end)

Planetary mission scientists have learned to expect the unexpected, and Pluto has certainly provided many surprises. One of the biggest has been its 'astonishing variety of landscapes', from the 1000km-wide uncratered plain of Sputnik Planum, bounded by mountainous regions, such as Al-Idrisi Montes and Hillary Montes, to cratered plains mantled with either brighter ices (north polar region) or darker deposits (Cthulhu Regio and Krun Macula), and rugged uplands marked with pits or elongated, raised 'blades' on the eastern section of Tombaugh Regio. This diversity provides evidence of a long and complex geological history, with some of it unexpectedly recent.

These features can be identified on the composite global map (Figure 6), created from images taken during approach and flyby, which shows the main regions, together with their provisional names (these have yet to receive formal approval by the International Astronomical Union).

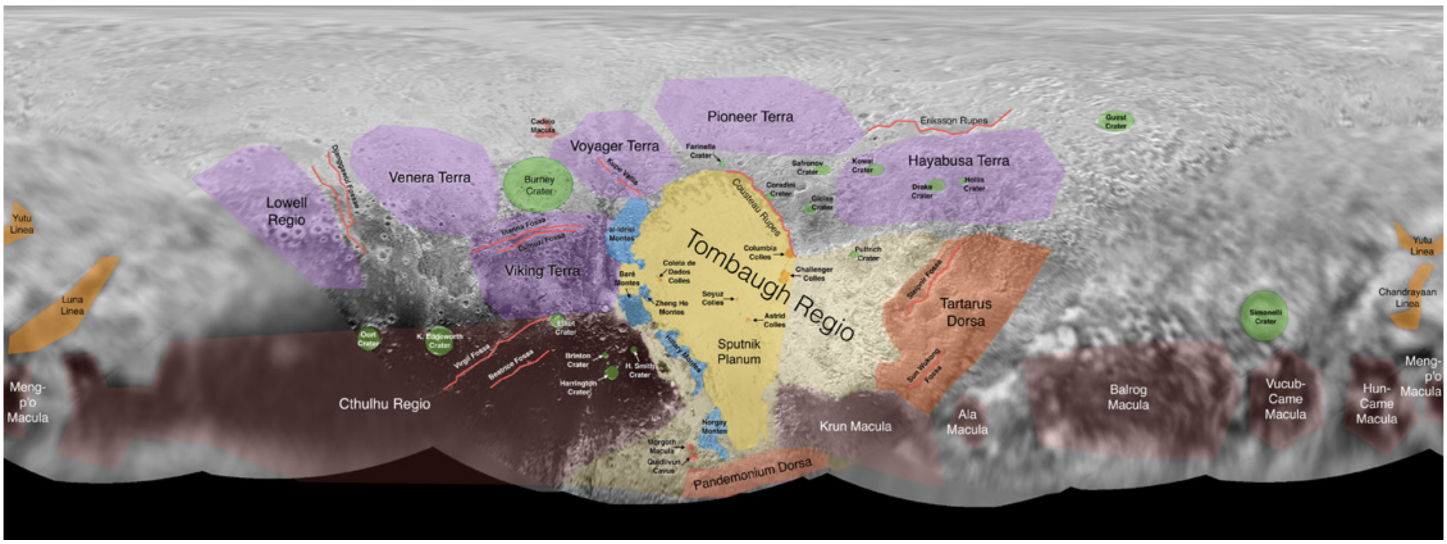


Figure 6: Informal names for regions on Pluto, based on a public naming campaign endorsed by the IAU, in partnership with NASA's New Horizons mission and the SETI Institute. Credit: NASA/JHUAPL/SwRI/SETI Institute

To understand Pluto's surface, we must remember that, at a distance of 30 to 50 times Earth's distance from the sun, Pluto is one of the coldest large bodies in the solar system with surface temperatures ranging from about only 33K (-240°C) to 55K (-218°C). Its surface composition and chemistry are quite different from those on Earth, although they do operate in a way to bring about analogous geological processes. So, rather than the Earth's rocky mountains floating on a mantle of magma, we find what Leslie Young describes as 'platoons of water-ice mountains floating in seas of frozen nitrogen – water is like the bedrock here.' It is the nitrogen, also the dominant component of Pluto's atmosphere, which appears to be involved in the most surprising surface processes observed - active glacial flow and the resurfacing of Sputnik Planum. This plain is located in what is probably an ancient impact basin, given the arcuate nature of the mountains bordering it on three sides.

Figure 7 shows the north-west edge of Sputnik Planum, where it meets Al-Idrisi Montes. There are flow patterns towards the mountains at the margin. There is also clear evidence of glacial flow channels in the oblique angle view of Sputnik Planum shown in Figure 8. At the surface nitrogen ice, which is structurally-weak compared to the rock-hard water ice, has a low enough viscosity to flow at the temperatures found on Pluto's surface. This surface flow is analagous to that of glaciers on Earth, with the volatiles flowing 'more slowly than silly putty but .... faster than glacial water ice on Earth.'

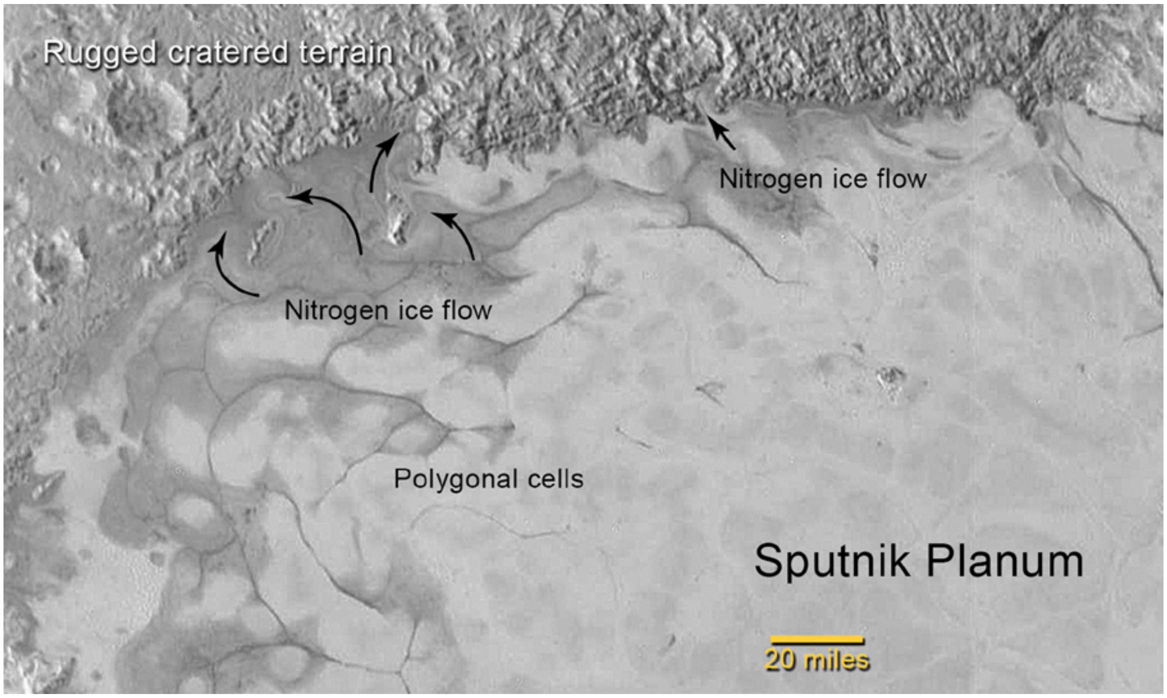


Figure 7: Polygonal cells and glacial flow on the northern margins of Sputnik Planum. Credit: NASA/JHUAPL/SwRI

The surface of the plain appears relatively young, being uncratered, and is broken into a network of polygonal cells, 10 to 40km across, with their centres rising some tens of metres above their margins, the latter characterised by darker X- and Y-shaped junctions. Modelling would indicate that this giant basin is probably filled with a 5 to 10 km-thick layer of frozen volatiles: nitrogen, methane, and carbon monoxide ices, but dominated by nitrogen ice. Within this layer solid-state convection may be occurring, with rising plumes of ice creating the surface polygons, at the edges of which the cooled material sinks back down. This can be likened to what happens in a pan of soup being gently heated from below, or a 'cosmic lava lamp.' The overturn rate is estimated at 1.5-3cm per year, which would put renewal times of Spunik Planum's surface at 500,000 to 1 million years, very young by geological standards. This would explain the absence of craters on its surface.

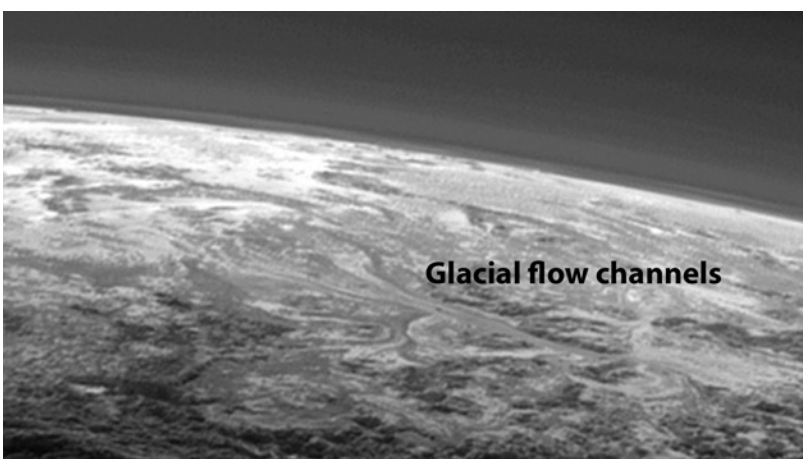


Figure 8: Evidence of glacial flow channels is seen in this oblique view of Sputnik Planum. Credit: NASA/JHUAPL/SwRI

The big questions posed by these discoveries are how such activity is driven on Pluto and what internal heat source(s) could create convection in this way? The accretional heat from the formation of Pluto would long since have been lost to space, as would any residual heat from early impacts, such as the one believed to have created the Pluto-Charon system. And there is no nearby large body to create tidal heating within Pluto, as is the case for example, for Jupiter's moons Io and Europa.

This leaves radiogenic heating – heat released slowly by the decay of radioactive isotopes within the dwarf planet. While an isotope such as ^{26}Al, with a short half-life of only 730,000 years, would have been depleted rapidly in the early days of the solar system, one possible candidate among others would be the isotope of potassium, ^{40}K, with a half-life of 1.3 billion years (the biggest contributor today to the Earth's radiogenic heat source). Potassium is also possibly more common within Pluto's rocky core (see Figure 9) than it is in Earth, as it is relatively volatile and would have boiled away more rapidly from the solar nebula in the early Earth's neighbourhood. And even if the heat source is relatively weak today, with an estimated radiogenic heat flux of roughly 3 mW per square metre as compared to about 80 mW m-2 for the Earth, it's thought that nitrogen ice, being a good thermal insulator, could store sufficient heat at depth to initiate convection.

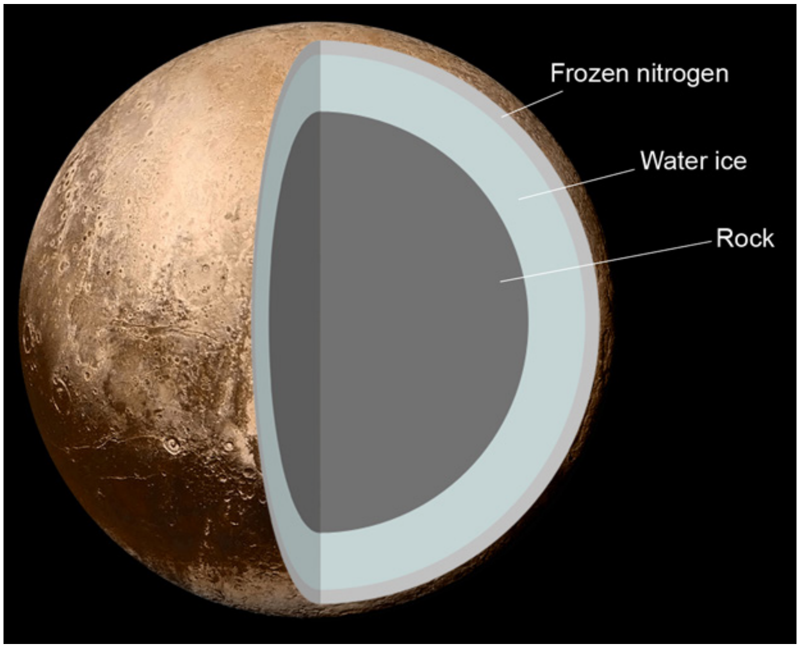


Figure 9: Pluto's density is 1.860g/cm³. This would imply a mixture of rock and ices. The rocky core contains radioactive isotopes which decay over time, producing a weak internal heat source. There is some speculation that faulting of Pluto's surface, which is indicative of past expansion of the dwarf planet, may be evidence for a residual subsurface liquid water layer some 100 to 180 km thick at the core–mantle boundary, like the sub-surface oceans postulated for Europa, Ganymede or Titan. Credit: NASA/JHUAPL/SwRI

Pits, blades, haloes and gunk

Pluto's atmosphere may well be replenished by this convective activity. Elsewhere, 'much of what we see … can be attributed to surface-atmosphere interactions and the mobilization of volatile ices by insolation.' These have, for instance, produced striking landforms on Sputnik Planum and Tombaugh Regio. At such low surface atmospheric pressures as on Pluto (about 10µbar – microbars – 100,000 less than Earth's, the equivalent of being at an altitude of 80 km on Earth) transfer of volatiles from the surface (ice) to the atmosphere (gas) currently takes place directly by sublimation. This leaves the terrain pitted with holes a few hundred meters wide by a few tens of meters deep. In some areas these are aligned (Figure 10), but the reason for this is not yet clear.

Interactions with the atmosphere may also explain the bizarre, so-called 'bladed' terrain in Tartarus Dorsa, east of Tombaugh region (Figure 11), described as 'texturally 'snakeskin'-like, owing to their ….scaly raised relief.' Typically a few hundred metres high and spaced a few kilometres apart, these long, steep, tightly-packed ridges align from north to south. Current theories to explain them include erosion from evaporating ices, deposition of methane ices, or even structures formed from primitive methane clathrates, with origins dating back to the proto-solar nebula.

Figure 10: Pitted terrain on Sputnik Planum. Credit: NASA/JHUAPL/SwRI

Elsewhere, large bright regions are seen where frozen volatiles from the atmosphere have been deposited, especially across more heavily cratered higher latitudes. In one region strange 'halo' craters were observed, the haloes apparently created by methane ices deposited on the crater rims, whereas the darker crater floors and intermediate terrain show signs of being dominated by water ice. Possible reasons for this distribution of ices, shown in Figure 12, are yet to be determined.

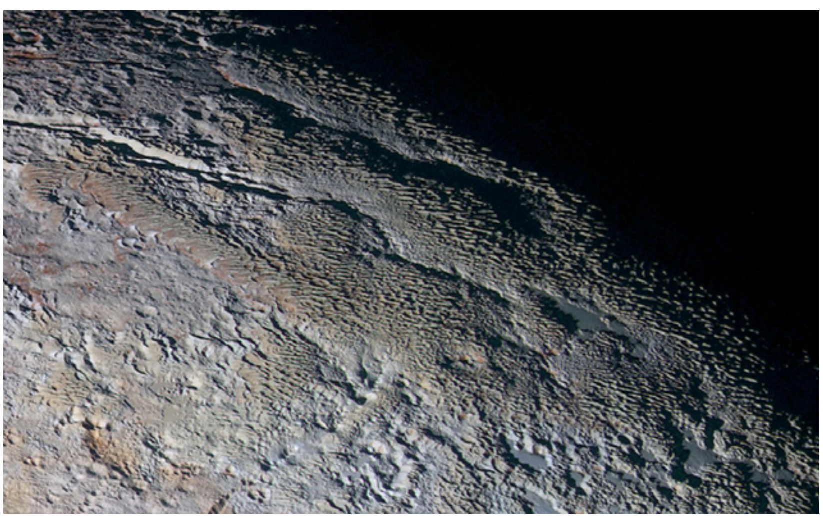


Figure 11: Bladed terrain in Tartarus Dorsa. Credit: NASA/JHUAPL/SwRI

Not all of Pluto's surface materials are ices. Deposition from the atmosphere has covered large areas of Pluto with reddish-brown material, first detected from Earth, and imaged in detail by New Horizons. Ultraviolet radiation from the Sun causes chemical reactions in atmospheric methane and nitrogen which create complex reddish-brown hydrocarbon molecules, known as tholins, like those already observed in the atmosphere of Saturn's largest moon, Titan. These fall from the atmosphere, covering the ground with a layer of 'gunk.' This blankets pre-existing relief – mountains, valleys, troughs, craters - especially along the equatorial regions, as Figure 13 shows. Cthulhu Regio is the most extensive such region, stretching almost halfway round the planet.

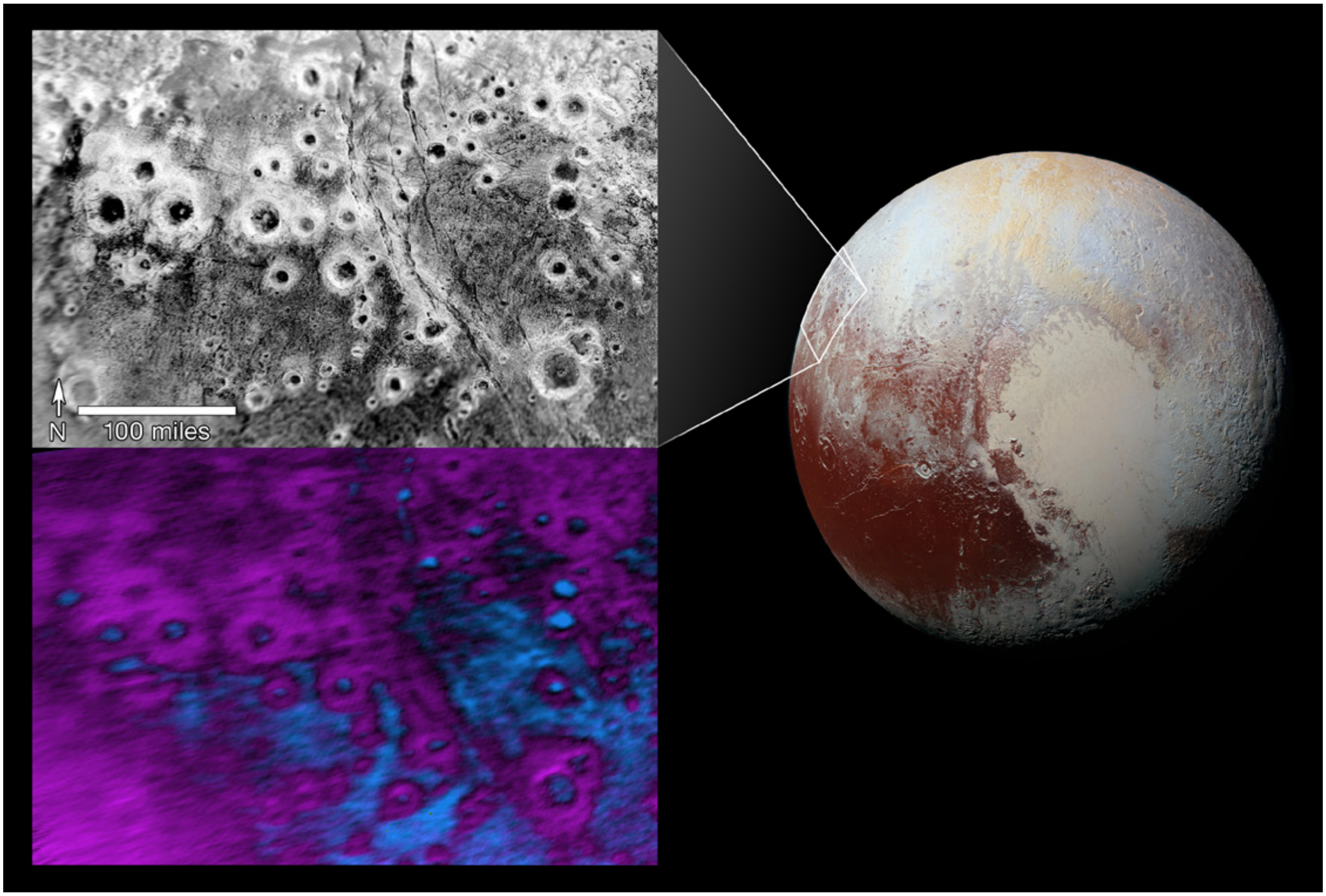


Figure 12: Halo Craters and methane distribution on Pluto. In the upper image, shown in visible light, the craters' bright rims stand out sharply from their dark floors and the surrounding terrain. In the lower image, created from composition data gathered by the Ralph/Linear Etalon Imaging Spectral Array (LEISA), there seems to be a correlation between the bright halos and distribution of methane ice, shown in false colour as purple. The floors and terrain between coloured blue, show evidence of water ice. The largest crater here is 50 km across. Credit: NASA/JHUAPL/SwRI

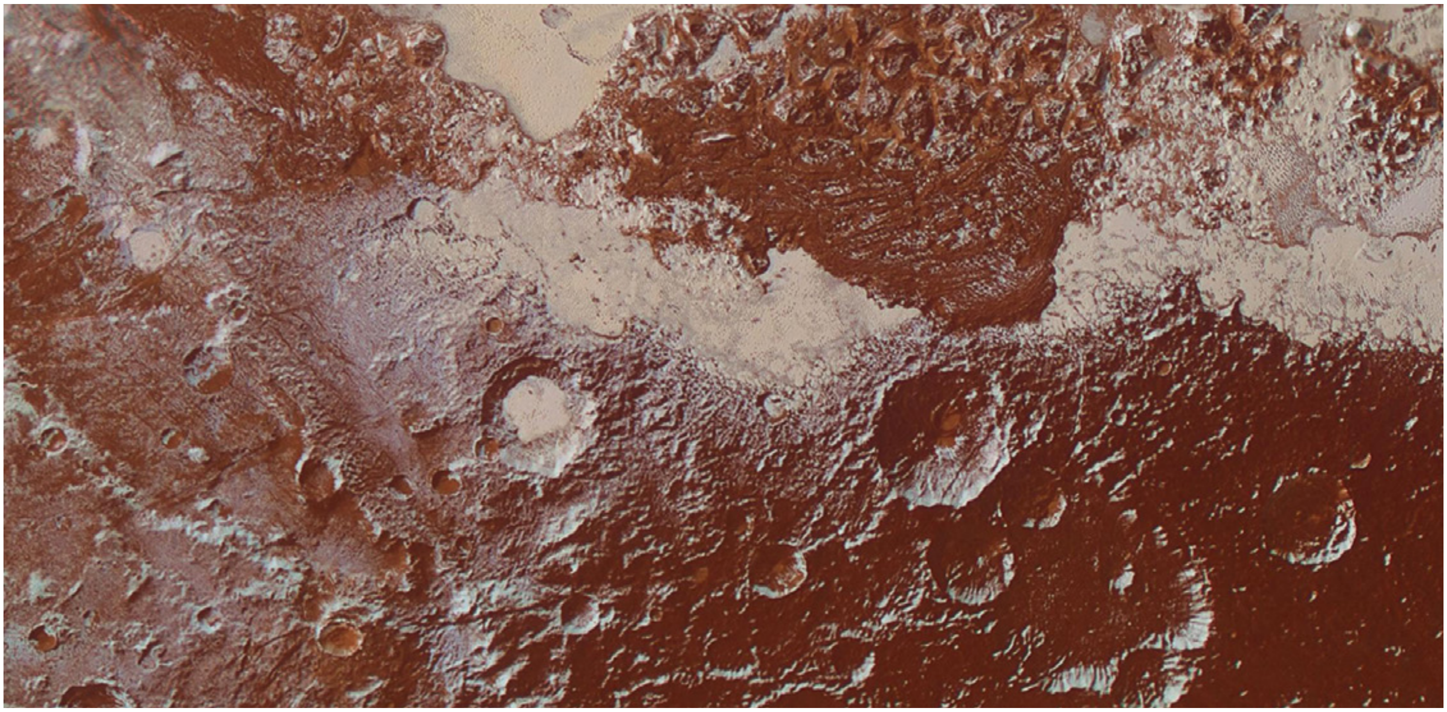


Figure 13: The eastern edge of Cthulhu Regio, at the margins of Sputnik Planum, a region where tholins have coated the pre-existing relief with a dark reddish-brown layer. Credit: NASA/JHUAPL/SwRI

Cryovolcanism?

If convective overturn is active in Sputnik Planum, one might expect to find signs of cryovolcanic activity too. Pluto's density, size and surface composition are similar to those of Neptune's largest satellite, Triton, which is believed to have been captured from the early Kuiper Belt when it was being perturbed by the migration of the outer planets. One of Voyager 2's biggest surprises at Neptune was the discovery of ongoing cryovolcanic activity on Triton. New Horizons did not detect any such activity at Pluto. However, two broad-based mountains south-west of Norgay Montes, Wright Mons (shown in Figure 14) and Piccard Mons, could be of volcanic origin. At about 4km and 6km high respectively, both have summit depressions which could be indicative of cryovolcanic activity. And, lacking surface craters on their flanks, they are possibly quite recent features geologically speaking.

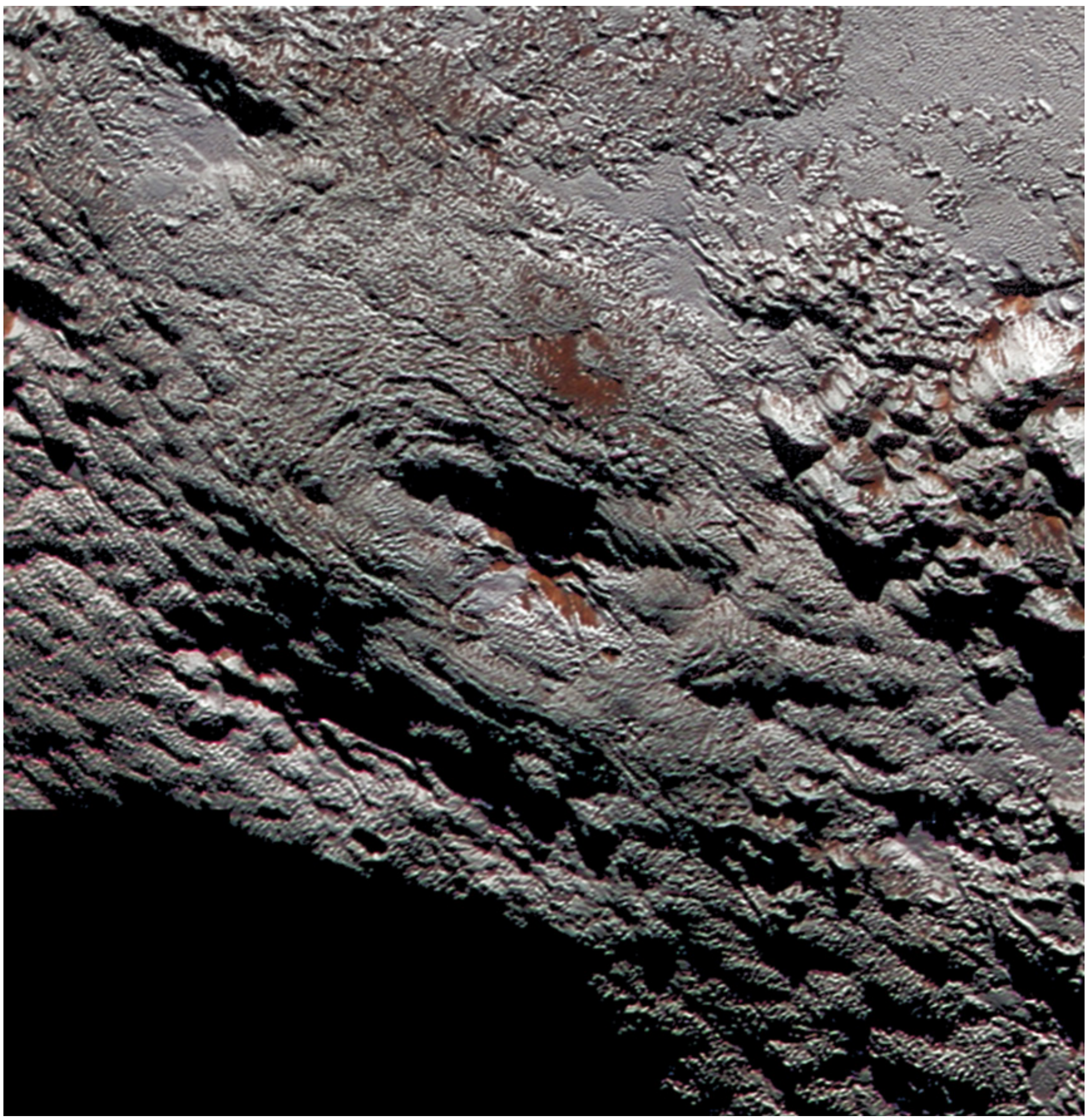


Figure 14: This rounded mountain, named Wright Mons, has what appears to be a summit crater. It is one of two candidates for evidence of possible recent cryovolcanism seen on Pluto by New Horizons. Credit: NASA/JHUAPL/SwRI

Dynamic atmosphere

We have spoken much above of apparent surface-atmosphere interactions. Pluto's atmosphere was a prime target for the New Horizons mission team. It is composed of roughly 90% Nitrogen (N_2), and 10%

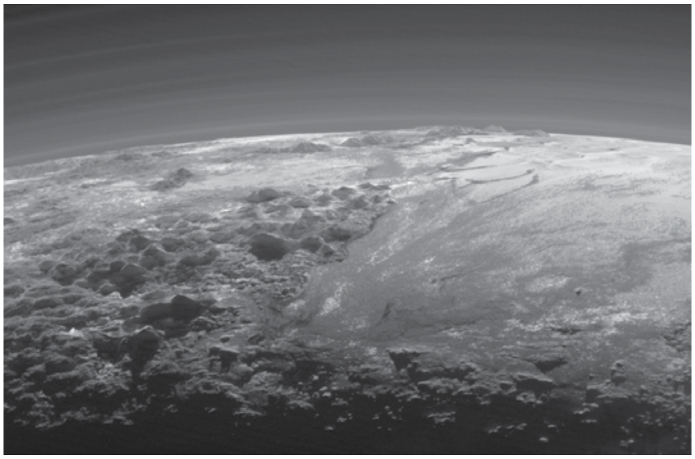


Figure 15: View looking back through Pluto's atmosphere towards the Sun, shortly after New Horizons' closest approach, showing the delicate structure and multiple haze layers of Pluto's atmosphere. To the left foreground and on the horizon are, respectively, the icy mountains of Norgay Montes and Hillary Montes, named for the first conquerors of Mount Everest. The smooth expanse of Sputnik Planum is to the right. Credit: NASA/JHUAPL/SwRI

complex molecules such as methane (CH_4), carbon monoxide (CO), which are in equilibrium with their ices on the planet's surface. Its intricate and dynamic structure was revealed as New Horizons looked back towards the Sun after flyby (Figures 15 and 16). As many as 20 individual thin (about 1.4km) layers of haze were visible to over 200km everywhere around the planet.

It has been suggested that Pluto and its atmosphere should experience extreme seasonal changes over its eccentric orbit, which takes it from 30 AU at perihelion to 50 AU at aphelion. These are enhanced by the dwarf planet's extreme axial tilt of 120° to its orbit, which means that at its solstices (when alternate poles are facing the Sun), a quarter of its surface is in continuous daylight, while another quarter is in continuous darkness. Changes in temperature may even lead to large periodic increases in the density of this atmosphere, perhaps even to the point where nitrogen could flow as a liquid at the surface. Some intriguing flow features and channels were observed, and what appears to be a frozen nitrogen lake (Figure 17) which might point to a time in the past when this happened. However, it is still uncertain if and how the extent and structure of Pluto's atmosphere may change with temperature.

Figure 16: Pluto's 'blue skies', imaged by New Horizons' Ralph/ Multispectral Visible Imaging Camera (MVIC). This blue colour results from the scattering of sunlight by very small particles, in this case probably tholins, soot-like particles created by complex chemical reactions of nitrogen and methane initiated by ultraviolet light from the Sun. Credit: NASA/JHUAPL/SwRI

It was initially thought that, as Pluto moves further out from the Sun in its orbit and temperatures fall, its atmosphere should gradually 'collapse', i.e. freeze onto the surface. However, data from New Horizons and ground-based observations currently suggest that it may remain gaseous, even at aphelion, although it wasn't possible to fully resolve the issue during the encounter. Leslie Young explains 'We were hoping to image the pole of Pluto currently in shadow by reflected Charon-light, to try and analyse the ice cover there. However, the haze layers in its atmosphere prevented us doing so, so we can't answer this question for now. We'll need to continue Earth-based observations of Pluto over the next few decades to see whether or not collapse does occur.'

Charon – chasms, craters and much more

The Pluto-Charon system is unusual since the two are tidally locked together, always having the same hemisphere facing each other. It is

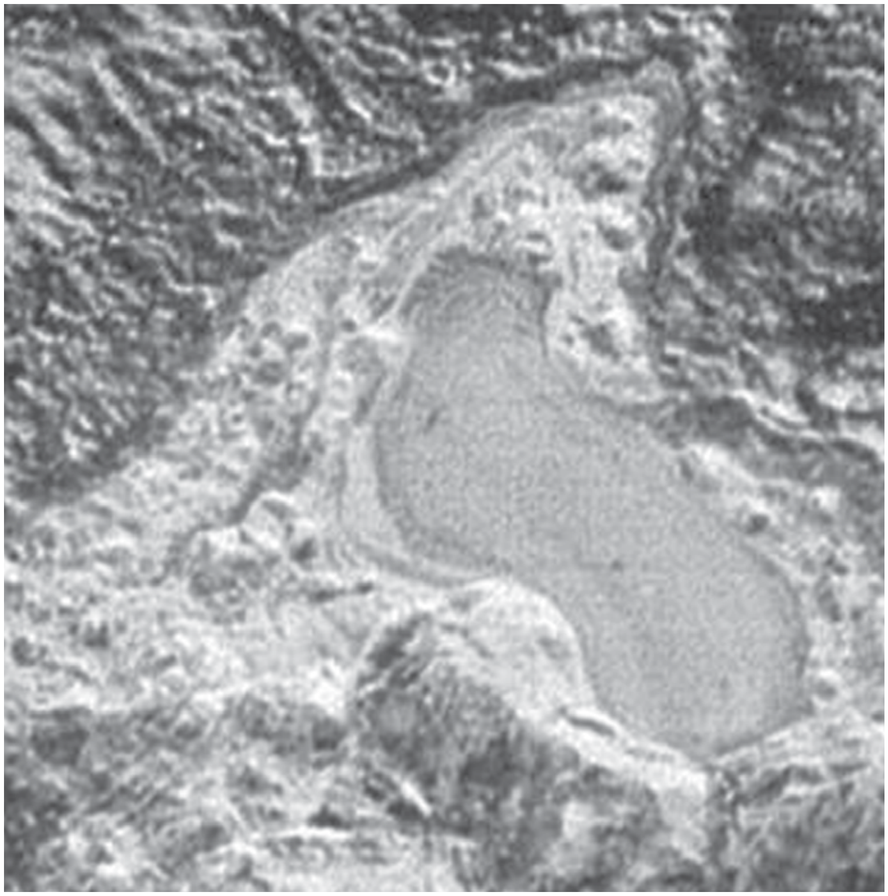


Figure 17: This flat feature in the Al-Idrisi Montes to the west of Sputnik Planum looks very much like a frozen lake surface. Credit: NASA/JHUAPL/SwRI

suspected that Charon was created by a large collision, some 4 to 4.5 billion years ago, similar to that which is thought to have created the Moon. The nearly circular orbits of Pluto's smaller satellites suggest that they were also formed in this collision, rather than being captured Kuiper Belt objects.

Despite being only half the size of Pluto, Charon also exhibits a surprising variety of landscapes and surface features, and shows evidence of a varied geological history. Some of these are shown in Figure 18 and described below. The northern polar region, Mordor Macula, is reddish (A), indicating possible alteration of methane deposits by solar radiation. Elsewhere, the northern hemisphere is ancient, rugged and cratered (B). There are unusual localised ammonia (NH3) deposits associated with a few bright craters (such as C). Ammonia ice hasn't yet been seen on Pluto, and its presence here is not fully explained as yet, although it must be fairly recent, since it is eventually destroyed by solar radiation and cosmic rays. It may a product of impact events or even local cryovolcanism.

The recent resurfacing on Pluto involving volatiles like nitrogen is not seen on Charon, perhaps due to its lower gravity and subsequent loss of such materials to space. Instead its surface is dominated by water ice. There is evidence of ancient resurfacing, especially across its smoother southern plains (F), but being smaller than Pluto, Charon's internal heat source was probably depleted early in its history. Locally, surface ices may have flowed under pressure, such as at the distinctive 'mountain in a moat' seen at G, where a water-ice mountain has sunk into less viscous crustal material.

Perhaps the most distinctive and spectacular features on Charon are its faults, often running in parallel series (D), and canyon systems, which

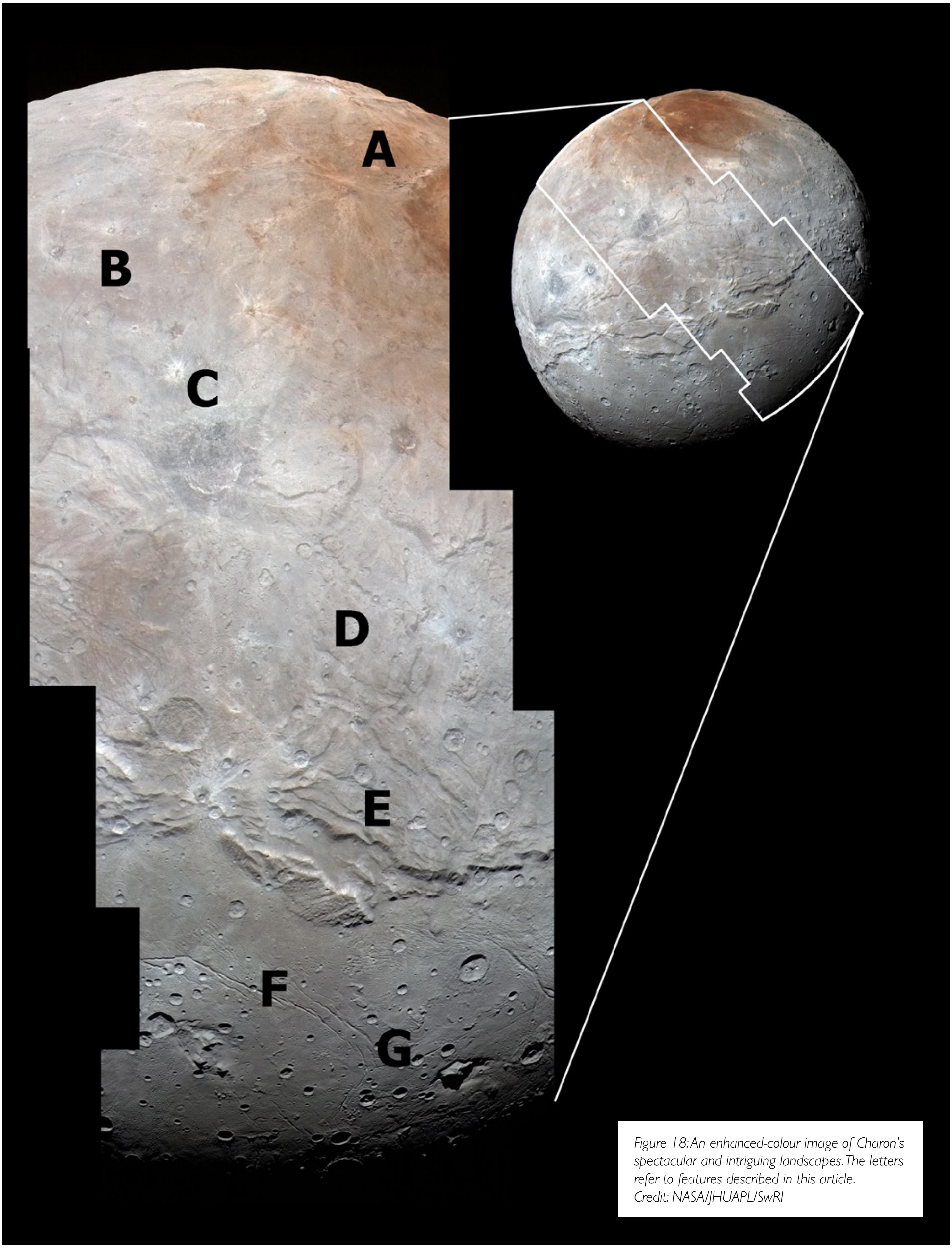


Figure 18: An enhanced-colour image of Charon's spectacular and intriguing landscapes. The letters refer to features described in this article. Credit: NASA/JHUAPL/SwRI

cut deeply across the hemisphere imaged by New Horizons. Serenity Chasma (E) is one of the largest canyons seen in the solar system at 1,800 kilometres long, over 50km wide and 5 km deep. According to mission scientists, they are indicative of the tectonic extension of Charon's crust. This would suggest that Charon once had an interior ocean which froze early in its history, causing a global expansion of about 1% or about 35km of shell thickening.

Pluto's small moons

Pluto's small moons are all brighter than Charon. Visual and spectroscopic observations during the flyby indicate that they all have water-rich surfaces and are probably of similar origin. Those which New Horizons was able to image more clearly show old, cratered surfaces. Their highly irregular shapes (Figure 19) suggest that they are the result of merged bodies, probably composed of debris left over from the collision which created the Pluto-Charon system.

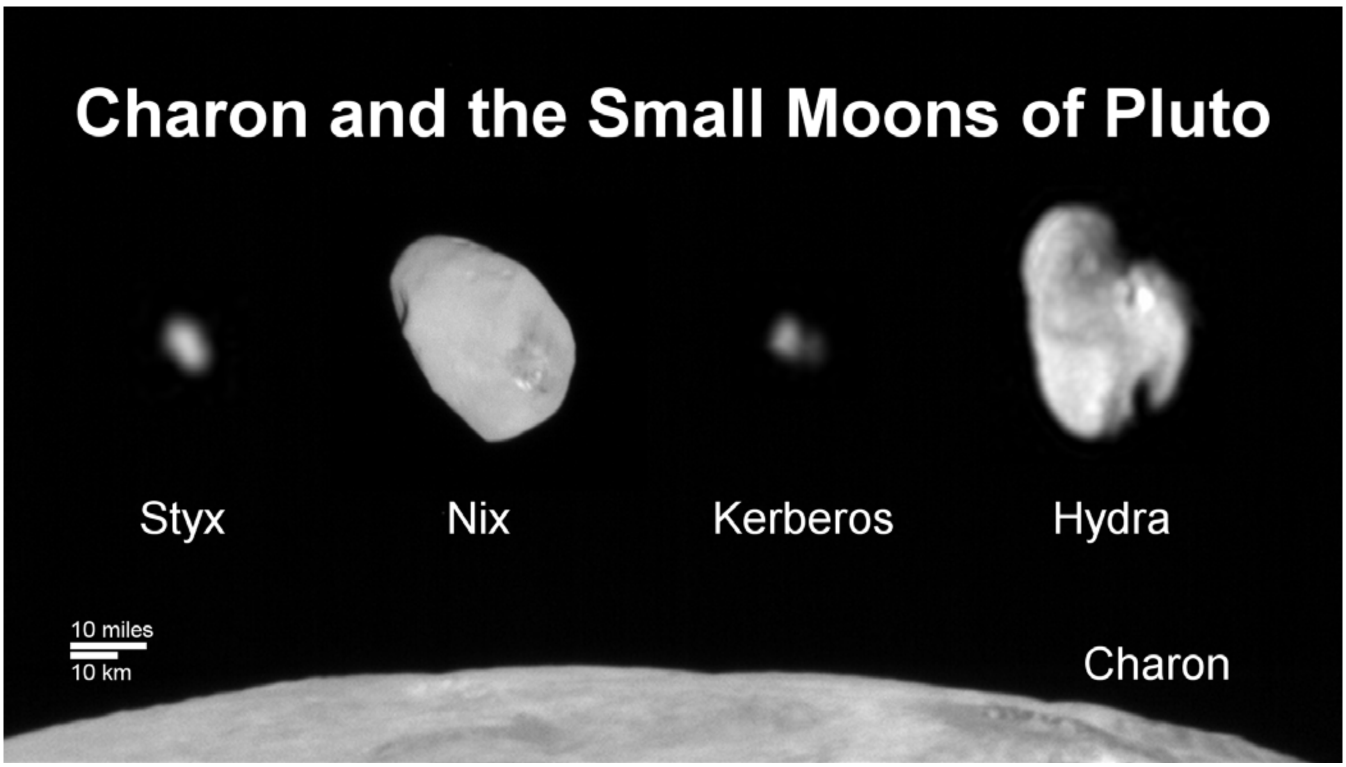


Figure 19: The small moons of Pluto, shown to scale with Charon. Credit: NASA/JHUAPL/SwRI

Interactions with the solar wind

As well as studying Pluto and its satellites, New Horizons was also equipped to study the environment surrounding them and especially the interaction of Pluto's atmosphere with the solar wind. Even this far from the Sun, it was thought that this continuous stream of charged particles from the sun - mostly high energy electrons, protons and alpha particles – would be eroding away the outer layers of Pluto's atmosphere. In the absence of a magnetic field to deflect the wind, this is what occurs at Mars. Pluto's bow-shock region (see Figure 20), where the solar wind collides with the outer layers of the atmosphere, is, like at Mars, quite abrupt – less than about seven Pluto radii, or 8,000km. However, atmospheric loss rates are low. The escape rate of nitrogen is about 10,000 times lower than that predicted before the encounter. This might be related to the colder than expected upper atmosphere observed by New Horizons, and 'has important implications for the volatile recycling and long-term evolution of Pluto's atmosphere.'

Like the Earth, Pluto has a long ion tail extending downwind beyond for a distance of at least 400 Pluto radii (about half a million km). As for the dust in the Pluto system which it was feared might be encountered, only a very low density of particles – barely 1 micron-sized grain per km^3 - was measured by the Student Dust Counter instrument.

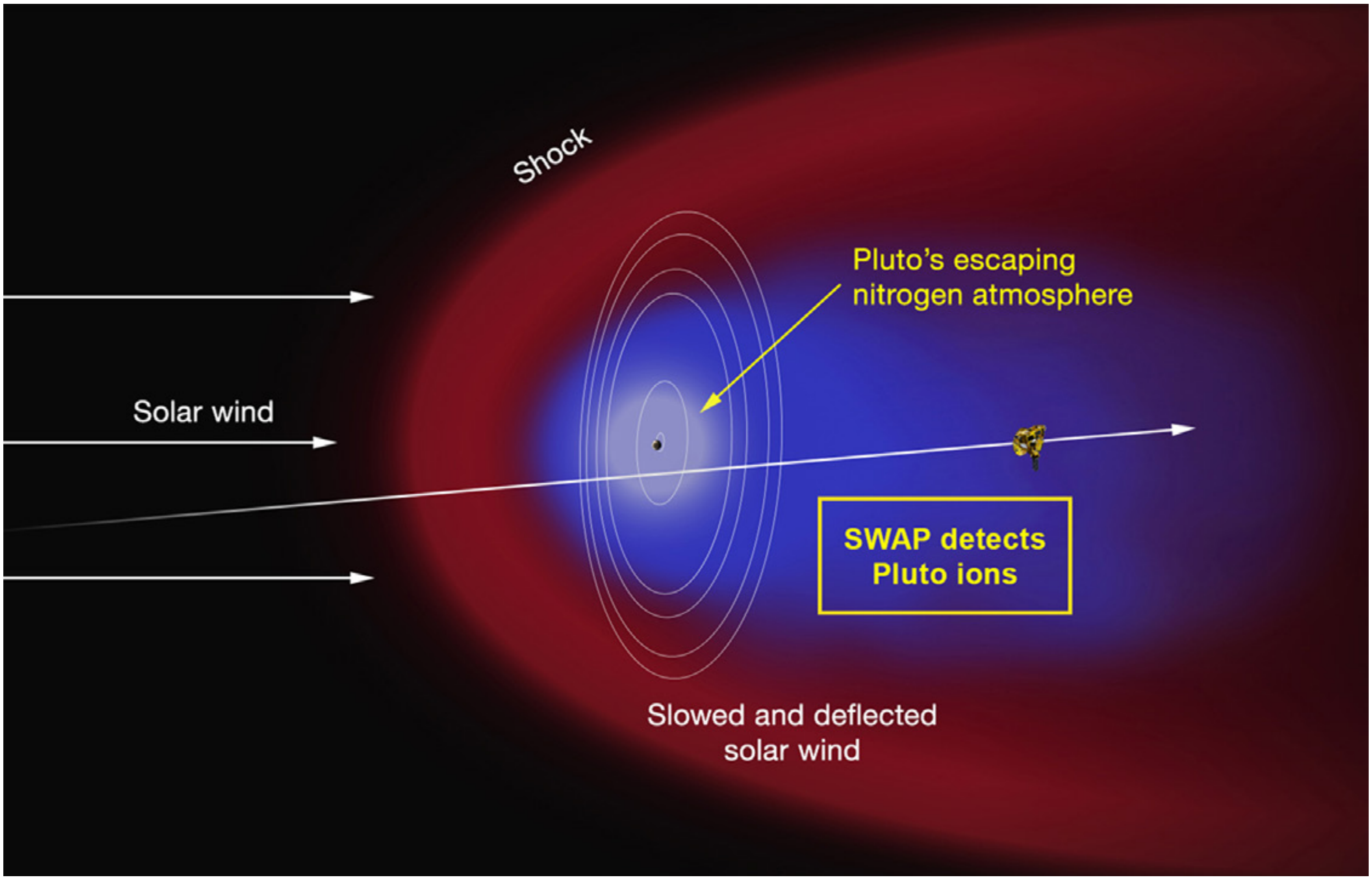


Figure 20: New Horizons' Solar Wind Around Pluto (SWAP) detector revealed interactions with the solar wind not dissimilar to those found at Venus and Mars. Credit: NASA/JHUAPL/SwRI

Pluto in context - looking ahead

What we have learned from New Horizons' encounter with Pluto, its moons and its interactions with the solar wind are obviously important in the context of the other members of the Kuiper Belt. Scientists now have a better idea of what they might discover out in the far reaches of the solar system, and that they can expect to find a much more active population of worlds than previously imagined.

There were many who were upset at Pluto's loss of planetary status and so-called 'relegation' to the status of 'dwarf planet' in 2006. However, ongoing discoveries confirming the population and extent of the Kuiper Belt have given it a much more interesting position for those studying the nature and evolution of the outer Solar System

Of 'dwarf planet' classification as it relates to the Kuiper belt, Leslie Young says 'I don't think it's a useful term. It's not used much at specialist level and I think it will die the death, especially as we begin to look at the Kuiper Belt in more detail. We need a whole new way of defining objects out here in the outer part of the solar system. We have Pluto, with its great diversity of features. Then Haumea is just the most astonishing creature! It's water-bright and it's the only KBO where we've found that the siblings are all water-bright. Then Eris is crazy-shiny! It has 96% geometric albedo. Yet, some of the other objects are as dark as comets, so how does that happen?'

Will we find convective surface renewal on other large bodies at the edge of the solar system, which may help to explain the high albedos shown by some of these? So far, we have seen that Pluto, Charon and Triton are all quite different. More surprises certainly await us as we explore the denizens of the Kuiper belt.

The New Horizons team hopes that their extended mission will help answer more questions about these. 'Our future is in NASA's hands,' says Leslie Young, 'but we now have a rendez-vous with 2014 MU69 and on our way we're going to be looking at other Kuiper Belt Objects too from distance. We'll also be using our plasma detection instruments to study the environment out here. Together with the two Voyagers we can try and build up a three-dimensional picture of the outer solar system environment using a series of one-dimensional shots. If possible we will continue gathering data as long as we can, maybe over a couple more decades.'

However long the mission is able to continue, it has already offered us a glittering prize in Pluto and its family of moons. Speaking of her involvement in the discovery of Pluto's atmosphere back in 1988, Dr. Young says that 'when you help rewrite the textbooks, that's an addictive thing. You want to do it again and again.' With New Horizons en route for its next encounter, and as we continue to unlock the secrets of the outer solar system, one senses that there is much more to be written.

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Note: A new Space Science Series book, "Pluto after New Horizons" (the current informal title for this sequel to the previous 'definitive' work on Pluto and Charon, edited by Alan Stern and David Tholen) is targeted for publication in 2020. Mission Principal Investigator Alan Stern will again be Chief Editor.

Glossary

VOLATILES - Elements or substances which condense (and vaporize) at relatively low temperatures, such as nitrogen, methane and water. Those which condense at high temperatures, like corundum (Al_2O_3) at 1758K or 1485°C, are refractory.

CRYOVOLCANISM - 'Cool' volcanic activity, where 'cold slurries' of volatiles such as water, ammonia or methane, erupt and flow across a surface, in the same way that molten rock erupts and flows as lava in warmer environments.

SOLID-STATE CONVECTION - Convection taking place in a solid, without the need for melting. For Pluto this would be within viscous, frozen volatiles.

TECTONIC - Related to the process of deformation within the crust of a planetary body and associated structural effects, such as faulting.

INSOLATION - Solar radiation reaching a planetary surface.

SUBLIMATION - Transition of a substance directly from a solid to a gas without passing through the intermediate liquid phase. This occurs with volatiles at Pluto's surface as its atmospheric pressure is too currently low for them to exist as liquids.

PLASMA - State of matter, created by adding energy (e.g. solar) to a gas and driving electrons from atoms, leaving electrically-charged particles or ions.

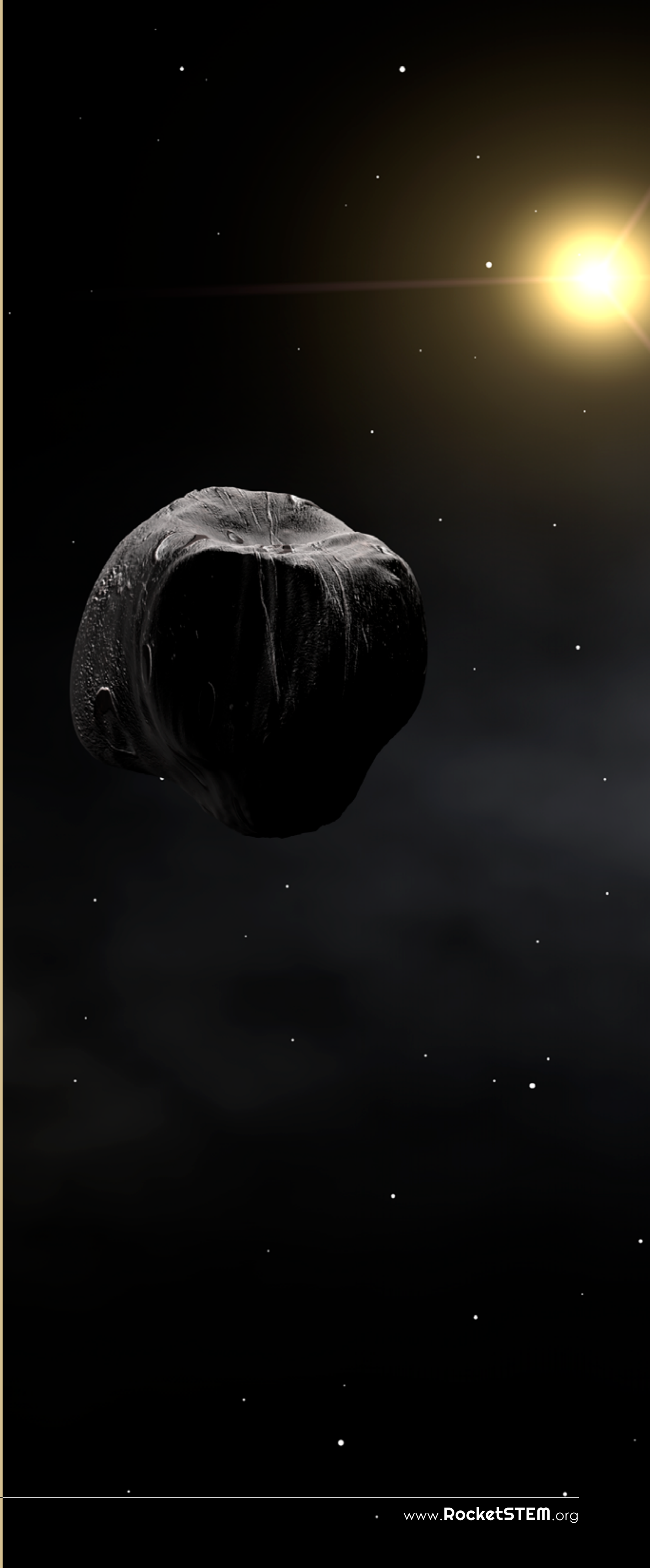
MAGNETOSPHERE - Region of space surrounding an astronomical object in which charged particles are controlled by that object's magnetic field.

(GEOMETRIC) ALBEDO - The fraction of the solar radiation falling on a body which is reflected by that body. Pluto's average albedo varies regionally from 0.49 to 0.66 – darker areas reflect only 49% of incident light, whereas the brighter areas reflect 66%. For comparison, Earth's average albedo is about 0.37 (37%) and our Moon's about 0.12 (12%).

ASTRONOMICAL UNIT (AU) - Mean distance between the Earth and the Sun, equal to 149.6 million km.

PERIHELION - Closest point to the Sun of any solar system body in orbit around it.

APHELION - The opposite, being the furthest point in its orbit from the Sun.



Artist's impression of the double asteroid Antiope. Both components have a quasi-spherical shape. The larger one was discovered in 1866. It was not until 2000, that it was realized that it consists of two almost-equally-sized bodies orbiting each other. Antiope orbits in the outer third of the core region of the asteroid belt, and is a member of the Themis family. Credit: ESO

Aquanauts splash down

The NASA Extreme Environment Mission Operations (NEEMO) 21 mission was conducted this summer as an international crew of aquanauts splashed down to the undersea Aquarius Reef Base, located 62 feet below the surface of the Atlantic Ocean in the Florida Keys National Marine Sanctuary. The NEEMO 21 crew performed research both inside and outside the habitat during the 16-day simulated space mission.

Credit: NASA